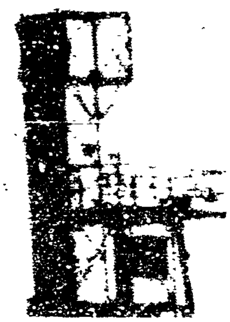
CONFERENCE ON ARTIFICIAL SATELLITES

PART C

VIRGINIA POLYTECHNIC INSTITUTE

BLACKSBURG, VIRGINIA

AUGUST 1963



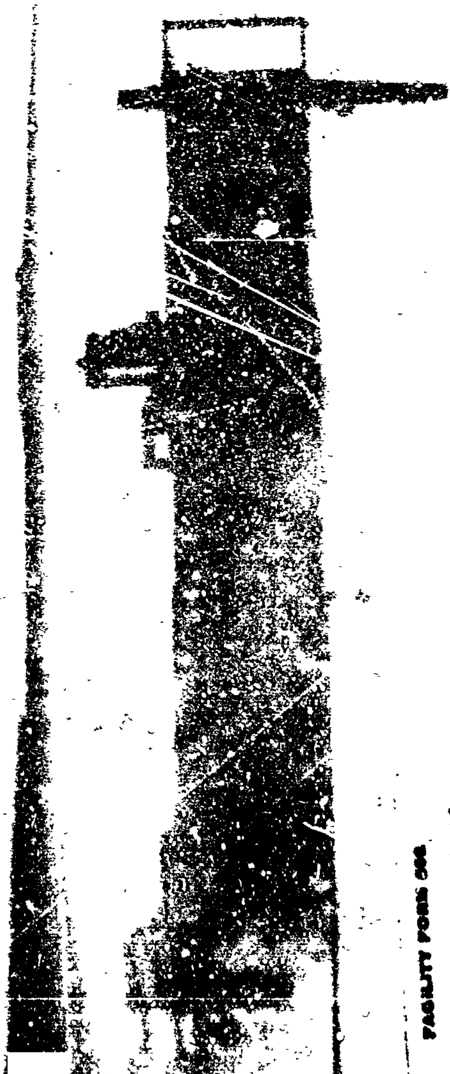


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TABLE OF CONTENTS

PART C

BANQUET ADDRESS

ADDRESS BY

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

LANGLEY FIELD, VIRGINIA

ADDRESS BY

DR. FLOYD L. THOMPSON

DIRECTOR OF LANGLEY RESEARCH CENTER

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

AEROSPACE - A CHALLENGE TO RESEARCH AND EDUCATION

The staff of Langley Research Center of NASA is pleased to have been able to assist the Virginia Polytechnic Institute in the development of this series of summer conferences on space activities held here at Blacksburg under the sponsorship and financial support of the National Science Foundation.

This year's program has given you a glimpse of the vast amount of scientific data on the space environment that have been accumulated by satellites and probes during the first 5 years of the space program. These data and their subsequent refinement and extension form the basis on which unmanned and manned space missions and vehicles will be designed to cope with the space environment. They also provide the information on which ground-based research facilities have been planned in order to provide the tools with which to solve the vehicle design problems that arise out of the hostile aspects of the space environment.

This evening, I should like to discuss in the light of my own experience at the Langley Research Center a problem that arises as we accelerate technical progress. My experience was originally associated principally with research in support of the development of aircraft, and now, more recently, has been concerned with research in support of the development of spacecraft. The problem that is becoming increasingly more pressing is that of developing the means for accelerating the effective distribution and assimilation of the newly acquired research information. I though that this subject would be of special interest to such a group as this composed largely of educators.

In 1926, when I joined the Langley Laboratory of the NACA, aircraft had been flying since 1903, the NACA was 12 years old, and actual research activity at the Langley Laboratory was only 7 years old. The charter of NACA provided that it shall study "the problems of flight with a view to their practical solution." Under a time schedule essentially geared to the development of military aircraft of increasing performance which development proceeded from generation to generation in approximately 7-year cycles, a laboratory was built up which provided the aviation industry with the definitive answers required to build their aircraft. Langley became a prime national center for the wind tunnels that provided the detail shapes and configurations and the air loads for structural design.

As World War II approached, the Government recognized that international competition for leadership in aeronautics required an expansion of aeronautical research facilities. In 1939 ground was broken for a new laboratory at Moffett Field, California, now called the Ames Research Center. In the following year a flight propulsion laboratory was started at Cleveland Ohio, and now called the Lewis Research Center. As each new center was started a nucleus of key people left Langley to staff the new centers. Langley, too, was expanded to meet the threat of war which came in December 1941.

During World War II, a peak in the LRC staff was reached as the unique facilities there were used around the clock to keep pace with wartime developments. During this period, although wind-tunnel activities dominated the Langley scene, adequate programs of research in aircraft structures, flight loads, and aircraft operations and hydrodynamics were pursued that maintained a broad base of knowledge in the entire field of aircraft design.

The stream by which the research effort of these laboratories was brought into the engineering community was by means of conventional technical notes and reports, supplemented by an annual inspection of facilities by aircraft executives and engineers. After World War II the pace of research activities and application had increased so that a major problem existed of getting research results to the potential users. The time delays inherent in preparing reports for publications and the assimilation and organization of the material by a few people inside each major aircraft company for use by the practicing engineer became unacceptable. As a solution to this problem there were held at frequent intervals special conferences which organized and presented to the industry the latest findings in broad areas of aerodynamics, of structural design, of aircraft loads, of flutter, and other areas of specialization. The written conference reports became guidebooks by means of which the more detailed reports, that still continued to flow, could be fitted into a more comprehensible whole.

During this same period there was not sufficient time for adequate textbooks to be written for use in the schools. To deal with this problem university conferences were organized for the special purpose of making new research information available to the academic community. There always was a small group of university professors for whom these conferences were not necessary because of their affiliation with research programs in their respective schools or other contacts and activities. However, for most of the engineering teaching profession access to the new knowledge created by the large research laboratories was through the normal channels of technical notes and reports supplemented by the university conferences.

The conference seemed to have supplied the solution of quickly informing the practicing engineer and the university professor of the research results at the level of activity established in the post World War II period. This level of activity did not long remain static for on October 4, 1957, the Russians launched the first artificial satellite.

Sputnik I suddenly aroused this country to the need for a greatly expanded space program. On October 1, 1958, the United States Government which recognized that if the exploration and exploitation of space for peaceful purposes was to be vigorously pursued, it could no longer be done independently by several branches of the Government, created the National Aeronautics and Space Administration. The NASA, although a new agency, was composed of already existing and functioning organizations of the Government, among which the NACA was the largest. Since World War II two new flight stations had been added; one for pilotless aircraft research at Wallops Island, Virginia, the other for high-speed manned aircraft at Edwards Air Force Base, California. The total complement of NACA was about 7,500.

The Space Act of 1958 consolidated, greatly expanded, and quickened the pace of this nation's program of space exploration. The IGY and other programs were already under way and were laying the foundation for this tremendous expansion of activity. For 5 years the NACA had been participating in the flight research project that resulted in the successful development of the rocket-propelled X-15 manned aircraft. The LRC was deeply involved in developing the concept for this research vehicle and in close support of the entire program of design, construction, and flight testing. This project is an example of one that served as a focal point for an intensive research effort. During the year prior to the enactment of the Space Act the LRC had formulated in considerable detail the concept for the project that later became known as the Mercury project. We formed a group that became the nucleus for the group that now forms the Manned Spacecraft Center at Houston, Texas. We continued to utilize our research facilities to support the Mercury project throughout its life.

These examples of focal points that lend objectivity to our efforts are illustrative of the manner in which we continue to operate as a major Research Center of the NASA. We are supporting the Gemini and Apollo programs in many ways and are deeply involved in conceptual studies of a Manned Orbital Laboratory that may later become an approved flight project. We have given a great amount of attention to the problems of lifting reentry bodies for application to the Dyna-Soar X-20 project or possible space ferry vehicles. In response to the research needs created by these new space flight systems and of space vehicles not yet defined as part of NASA's official program, the face of Langley Research Center has changed. A hard core of wind tunnels still remains to pursue the aeronautical development program that is exemplified by the Supersonic Transport which will fly in commercial service at speeds of 2,000 mph, but to them there has been added a complex of new laboratories.

High-temperature wind tunnels exist for structural tests with stagnation temperatures as high as 3,500°F; also arc heating jets which are capable of producing temperatures as high as 15,000°F to test materials to be used to protect reentry vehicles, and a host of vacuum chambers ranging in size from a few cubic feet to a few tens of thousands of cubic feet in which vacuums approaching that of space can be produced. These chambers permit the various kinds of research tests to be accomplished for which the atmosphere at sea-level pressure would interfere; dynamic tests such as the infraction of the thin-walled spheres of the Echo series; separation of rocket stages; radio wave absorption in rocket exhausts; evaporation of surface films.

LRC has wind tunnels and special devices for creating flows with air or special gases over a wind range of speeds and pressures. At the upper range of speeds temperatures are generated that are sufficiently high to excite the gas molecules so that they radiate energy in the visible and infrared frequency ranges.

Real-time dynamic simulators exist or are being built which will permit research to be carried out on the control problems of manned space vehicles. Such simulators permit research engineers to study the systems required and permit pilots to fly on earth those missions for which no opportunity for practice exists in space; the rendezvous of the Gemini and Agena vehicles, the descent and ascent of the astronauts from the lunar surface.

To study the effects of the nuclear particles in space, LRC is now building the Space Radiation Effects Laboratory, which will be operated by the newly formed Virginia Associated Research Center (VARC). Energetic protons and electrons will be produced which can simulate the energy range of those found in space. This laboratory will provide the capacity to explore the interaction of these damaging particles with spacecraft materials and systems. Micrometeorite accelerators are available to study the impact of microscopic size particles on space vehicle surfaces.

The staff of the LRC which now numbers 4,200 people is accepting the challenge to exploit these new facilities in order to provide NASA and American aerospace industry with the new knowledge to plan and to build reliable space systems. But how shall all this new knowledge be introduced into the industry that requires it for successful operation? And, especially how shall it be introduced into the educational institutions which are both the repository for it and means by which it is introduced to the new generations of students who are emerging? The problem is more staggering when one realizes that to our output must be added that of other centers and sources. As far as our association with industry is concerned, we are still making use of the specialized conference, but at an increasing rate. Already in 1963 we at LRC have organized major conferences on shell problems of space structures, manned control of space vehicles, and the design of a manned orbiting laboratory, and a series of smaller conferences in more detailed areas such as microelectronics. We are now planning for next month a 2-day classified conference on the current state of knowledge on all aspects of the design of a supersonic transport.

As it has always been, a good deal of this information is detailed, and of transitory interest, but if the fraction of it that is significant today as it was in the past, must we not try to discover new mechanisms for the transfer of this information into the scientific and technical community? Of special concern is the introduction of this information into the educational system, not only for the creation of new members of the professional people but also for those whose knowledge must continually be updated.

It has been suggested that one solution of this problem can be provided by associating educational communities close to major research centers now situated in many parts of the country. Great credit is due the educational leaders of the Commonwealth of Virginia, who in recognition of the problem of maintaining a continuing association of the noneducational research community with education institutions have or are in process of establishing a new graduate center near the LRC. This center, authorized under enabling legislation passed in the 1962 meeting of the General Assembly, will permit the three major institutions of higher learning in Virginia, who are now engaged in graduate education and research, to operate a major laboratory of the Langley Research Center, and also to establish a cooperative program of graduate education in science and engineering. We believe that such a center can do much to improve the flow of new knowledge into the usual stream of educational activity.

Many other things are being done and in the future many new methods and procedures probably will be developed to accelerate an effective distribution and assimilation of the rapid flow of new research information. This is a matter that is receiving a great deal of attention by the NASA, but I would like to suggest that the advice and inventiveness of educators such as those here tonight would be of great benefit. We believe that this meeting here at Blacksburg serves as a very important mechanism in dealing with this problem. Certainly it must serve to shorten the channel that connects various sources of significant new research information with the teaching staff of colleges and universities over a wide area. This is an important reason for our desire to assist in the development of the series of summer conferences on space activities here at Blacksburg.

In closing, I should like to quote from the words of a man not an engineer or scientist, but a keen observer of the modern American scene, the President of Harvard, Nathan Pusey - "We live in a time of such rapid changes and growth in knowledge that he who is in a fundamental sense a scholar - that is a person who continues to learn and inquire - can hope to play the role of guide. Indeed, it is not too much to believe that we may now be coming into an Age of Scholars, for we have created for ourselves a manner of living in America in which a little learning can no longer serve our needs."

PROJECT RELAY

BY

JOHN D. KIESLING

RADIO CORPORATION OF AMERICA

PRINCETON, NEW JERSEY

PROJECT RELAY

by

John Kiesling

INTRODUCTION

The capabilities of existing long-range communications facilities, already pressed by present demands, will be inadequate to accommodate anticipated traffic within the next decade. One of the possibilities for providing the needed increase in communications facilities is the satellite communications system. The communications satellite has the potential ability to provide long-distance communication at microwave frequencies, with bandwidths available permitting the transmission of television of many simultaneous voice messages. This can be a new and reliable link in long-distance, transoceanic telephone and telegraph communications, as well as new means for intercontinental radio and television transmission.

Relay

Relay is a communications satellite built by RCA for the National Aeronautics and Space Administration. The satellite was launched from the Atlantic Missile Range on December 13, 1962 by a Thor-Delta rocket and provided experimental communication links between North and South America, and between the Americas and Europe. This satellite continues to perform satisfactorily after eight months in orbit. A second Relay satellite will be launched in late 1963. Project Relay has the following objectives: (1) to investigate wideband communications between distant ground stations by means of a low altitude orbiting satellite; (2) to measure the effects of the space environment on such a satellite; and (3) to develop operational experience in the use of a satellite communications system.

The satellite contains an active repeaterto receive and re-transmit communications signals between stations in the United States and Europe, and the United States and South America. Communications signals evaluated are an assortment of television signals, multichannel telephony, and other communications.

A major part of this project, a ground station network consisting of six Relay ground stations located in the United States, South America, and Europe, has been developed to serve as the terminus of the communication links. This ground station network was developed through the cooperation of a variety of governments, agencies and private companies.

Project Relay is also used to perform experiments which will provide the following information: (1) a measurement of radiation damage to critical components such as solar cells and silicon diodes, and (2) the monitoring of radiation encountered at the orbital altitudes. The results of these experiments are being correlated with measurements of integrated flux, and energy levels of protons and electrons to obtain experimental estimates of component lifetime.

Communications repeater satellites present special problems to the designers and users of these equipments. The satellite environment (including the launch environment), spacecraft acquisition by the ground station, the inaccessibility for repairs and routine maintenance, and thermal and power supply problems impose special constraints on the design. Most of these problems are relatively new and solutions are either not readily available or not proven by experience. These are the principal problems that require investigation, and the experiments of Project Relay can provide information necessary to arrive at possible solutions.

The communications satellite must perform a variety of critical functions in order to remain operational. These functions, as they apply to Relay, are summarized as follows:

1. Communications: Microwave repeaters, as such, have been operational for many years in overland routes. However, when these techniques are extended for use in satellites, limitations in size, weight, power consumption and thermal dissipation quickly become apparent. These problems provide the challenge for the equipment designer. Inaccessibility for repair places critical importance on the reliability of the circuits and components, and the hostile environment (vacuum, radiation) requires extensive consideration.
2. Command: A series of command functions (and a command communications link) must be provided. For instance, the communications system must be turned off when not needed in order to conserve battery power, and other functions must be executed on command, at the proper times.
3. Tracking: Beacon signals at 136 MC are provided to assist tracking stations in establishing the orbit, and providing tracking information to the ground station. A microwave beacon is also provided to assist the large ground station antenna (with small beam widths) in locking onto the satellite.
4. Telemetry: Telemetry is required in order to assess the state of the various satellite subsystems, and as a diagnostic aid should trouble develop.
5. Power Supply: The power supply must provide all the primary power for the satellite. On Relay, the solar cells are not capable of supplying the peak loads required to operate the communications equipment, hence batteries are necessary, and, hence the communications equipment must

operate at a low duty factor. This problem must be overcome in an operational system by either providing a larger solar array or using other forms of primary power generators, such as nuclear power supplies, or radio isotope power supplies.

6. Stabilization: The satellite is stabilized in space by spinning it around its (spin) axis. If this spin axis is aligned correctly in space, a toridal antenna pattern will provide sufficient "look angle" coverage. Relay is spun at about 160 rpm and its moment of inertia about the spin axis is ten percent higher than it is about other axes so the spin is made stable.

7. Attitude Control: Although the spin axis is fixed in space there are small torques applied to the satellite which would cause the spin axis orientation to change. These forces are motor torques due to the interaction between the earth's magnetic field and the magnetic dipole (residual magnetism) of the satellite and the currents flowing through the electrical circuits of the satellite. Another source of torque is the gravity gradient. The nodal regression of the orbit, due to the non-spherical shape of the Earth causes the plane of the orbit to rotate, which, in turn, causes an apparent shift in the spin axis orientation. On Relay, the dominant torque is due to the Earth's magnetic field, A torque coil consisting of many turns of wire is wound around the "equator" of the satellite. When the satellite is in the correct position, a current can be made to flow through this coil (on ground command) to apply a torque to correct the satellite attitude. Other methods of torqueing may be used (e.g., gas jets, rockets, plasma engines).

DESCRIPTION

The communication system used in the Relay spacecraft is composed of three major subsystems: (1) wideband communications, (2) telemetry, and (3) command control. Each active component of the communication subsystems is redundant, with the exception of the telemetry encoder. Weight limitations precluded redundancy for this unit.

The purpose of the wideband communications subsystem is to perform experiments on the following types of transmission: television, multichannel telephony, high bit-rate digital data, facsimile, telephoto multichannel teleprinter transmissions, etc. Specifically, the subsystem will provide the following: (1) television transmission in either direction, between United States and European stations including the transmission of test signals and patterns, and a tie-in with television networks in the United States, England, France and West Germany as both program sources and for the distribution of Relay Programs; (2) multichannel, two-way telephone service of 12 channels each between the United States and Europe, and between the United States and Brazil, and (3) multichannel, record communications service and high-speed data transmission between the United States and European Stations, and between the United States and Brazil.

In addition to communications over the link, a variety of television, telephony and other communications techniques can be studied at a particular ground station by sending and receiving at that station. This will also allow a study to be made of the detailed link performance.

The telemetry system will provide remote monitoring of the critical electrical parameters of all subsystems carried on board the spacecraft. In addition, either telemetry transmitter can be operated without modulation to provide a 136-megacycle carrier for spacecraft tracking operations by the NASA Minitrack System.

The command control system will permit radio remote control of all switched functions in the spacecraft.

The ground station transmitter for the television and 300-channel telephony is a frequency-modulated 10-kw klystron with a spectrum bandwidth of 10 to 14 megacycles (Mc) per second. An 85-foot parabolic antenna or a 68-foot horn will be used depending on the particular ground station. The transmitted power to the satellite is sufficient so that the system noise threshold will be due almost entirely to the satellite to ground link. For the 12 channel two-way telephone circuit a 10-kw klystron with a 1-Mc-per-second bandwidth will be used with a 40-foot or 30-foot parabolic antenna. The ground transmitter frequency is 1725 Mc.

The ground receivers will use a variety of front ends consisting of either maser or parametric amplifiers.

The satellite repeater performance is characterized by hard limiting and modulation index tripling. The tripling is required because of the limited bandwidth of the ground transmitter. The output power for each of the two-way telephony channels is four watts. A 4080-Mc, 200-mw beacon signal is also provided as a tracking aid.

While the object of the experiments is to study the feasibility of satellite-type communications links, and considerable care has been exercised in the design of the links in order to achieve this objective, the link is not an operational system and the ability of various countries and organizations to participate in the program has been dictated by the availability of equipment and funds.

The transmission medium characteristics are being examined, these are attenuation, attenuation stability, phase characteristics, interference, noise, time delay and other characteristics that may be of interest. No special anomalies have been observed to date except for some refraction at the horizon.

The satellite receiver signal strength, telemetry data, and attitude are being correlated with ground stations performance (antenna elevation, pointing error, weather conditions and doppler shift).

EXPERIMENTAL RESULTS

Relay was launched on December 13, 1962 from the Atlantic Missile Range. Information for the launch and from the first orbit confirmed that the satellite had achieved the desired orbit. At the present time, Relay has accumulated almost 2000 orbits and successfully "relayed" television, telephony and other data transmissions between North America and Europe and two-way telephony between North and South America. The programming thus far has included the Mona Lisa dedication ceremonies with President Kennedy relayed to Western Europe and Italy; a telephone message to Europe by the astronaut, John Glenn, a message by the Secretary of State, Dean Rusk, relayed to South America via the Rio ground station, a portion of the Disney Show, in color and several news stories of significant interest. Many more programs are planned. The ground stations in North America and Europe have reported excellent performance and quality, thus demonstrating the wideband capability of the Relay Satellite. Programming to and from South America has been adequate but not as spectacular because of the small station there (30-foot antenna and 400°K receiver-noise temperature).

Several difficulties have been encountered with the Relay Satellite equipment. The most troublesome has been an intermittent failure of a series power transistor in the power supply voltage regulator which provides regulated voltage to one of the wideband transponders. This regulator-transistor also acts as a switch to disconnect the wideband transponder when not in use. The germanium transistor developed sufficiently high (leakage current), so that this transponder turned on after launch and could not be turned off. The batteries discharged under the constant high current drain and the satellite was not useable. The leakage was believed to be associated with the dewpoint of the gas inside the transistor cap which was not sufficiently low to prevent ice-forming in the transistor at low temperature. After about two weeks the trouble cleared and the satellite became operational. The trouble reappeared in March 1963 when the satellite was in partial eclipse but cleared again after several days. Experiments are continuing to determine the precise failure mechanism, although it is believed at this time that the difficulty is not associated with the space environment directly. One of the three batteries became inoperative during March because of a defective charge regulator. Due to the redundant circuitry used, the satellite is still completely useable except for a lower duty factor.

Spurious commands have been observed frequently in the spacecraft, that is, equipment sometimes turns on or off without ground command. It is not yet established whether this problem is due to a fault in the satellite or to spurious commands caused by radiations from ground transmitters such as Airport Radio Control, etc. So far it has not been possible to duplicate these spurious commands with ground experiments.

Radiation has taken its toll of the spacecraft solar cell system. The solar cell array initially had 130% of needed capacity based on 100 minutes of operation a day, and the array capability decreased to about 50% of this capacity after 8 months in orbit. This degradation only means that the operating duty factor of the satellite will have to be decreased as times passes. It is believed that the degradation is less than expected because the Van Allen radiation is somewhat less than expected. The second Relay satellite has been fitted with N-on-P solar cells which are much more resistant to radiation. This second satellite will be launched during the latter part of 1963.

FUTURE EXPERIMENTS

Before a commercial communications commission using satellites (either at non-synchronous or synchronous altitudes) can be considered as state-of-the-art, additional experiments must be performed and certain techniques advanced. These improvements are in the general areas of satellite and launch reliability. One of the fundamental costs of a satellite system will be satellite replacement cost including launch cost. Substantial improvement of the mean time between failures (MTBF) of the satellite equipment can be achieved by reducing the complexity of the equipment, especially the satellite power supply, and by judicious application of knowledge of the space environment to the design of components and circuits. Experience with satellites like Relay provide this knowledge.

Multiple launch is another way in which operating costs can be reduced. This has not been attempted with any communications satellite as yet, primarily because the boosters used in these programs do not have the capability. This situation will improve when more advanced rockets become available.

New types of power supplies are certainly required for an operational system. If sufficient average power were available to the satellite equipment, the equipment could be left on indefinitely, thereby improving the basic reliability of the equipment itself, as well as eliminating a complicated command system, and eliminating a battery-type power supply, with all its complexity, to handle the peak load. Solar cells are capable of the average power, but the solar arrays become large and heavy, and of course, the satellite is not useable during eclipse. Nuclear power supplies now under development may provide the answer.

Higher orbits with steerable anteannas and station keeping (e.g., the satellites are fixed in position with respect to one another) provide more coverage with less satellites and less average power per satellite, and as much, promise to be a fruitful area for experimentation and growth.

One can visualize a satellite communications system initially employing a small number of medium altitude, randomly spaced, spin-stabilized satellites like Relay to provide limited communications ability for, say, the North Atlantic Community. As technology advances, new satellites with greater sophistication in the areas named above could be launched, extending the coverage to other points of the glove, and reducing outage time. The system could grow to the stationary satellite system (synchronous) when the technology permits, while providing a substantial communications capability in the interim. This procedure would defer a firm commitment to the more sophistocated systems until these systems were state-of-the-art.

Of course, the exact form and timing of these experiments depends upon many factors. Government participation in experiments, the effectiveness and needs of the newly formed Communications Satellite Corporation, the needs of foreign governments and agencies, the funds available, and political considerations, all combine to complicate a situation which is already complicated in the technological sense. It is probably safe to state that the experiments will be performed, that a satellite communications system will eventually evolve, and to leave the time scale and the participants an open question.

N65 15499

MANNED SATELLITE PROGRAM

SATELLITE DATA RECOVERY AND TRACKING SYSTEM

BY

GERALD M. TRUSZYNSKI

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

WASHINGTON, D. C.

SATELLITE DATA RECOVERY AND TRACKING SYSTEM

by

Gerald M. Truszynski

National Aeronautics and Space Administration

Gentlemen, my purpose in being here today is to describe for you some of the NASA accomplishments and plans in the area of Tracking and Data Acquisition for manned satellites. I would like to begin with a very brief description of the Manned Space Flight Network as it was configured for the Mercury program, followed by a discussion of the changes that were made in the Network for the longer duration orbital flights of Schirra and Cooper last October and May respectively. Next I will describe how the Network performed in terms of its ability to provide mission operational control and in terms of its accuracy and its reliability. Finally, I will discuss the augmentations planned for the support of the upcoming GEMINI program.

The geographical locations of the stations in the original Manned Space Flight Network are shown on the first slide. (Slide 1) There is a total of 16 stations which includes two ships; one ship in the Atlantic and one ship in the Indian Ocean. These stations have been publicized on TV and in the news media and I am sure everyone is generally familiar with their general distribution. The basic rationale used in setting up the Network however, is not generally known.

In planning these station locations and their equipment, the approach varied considerably from that used for scientific satellites and that used for unmanned lunar and planetary missions because of the difference in mission requirements. These differences included the requirement for data flow and computations in near real time as well as the need for mission flight control capability and, of course, a primary consideration of astronaut safety. On the Mercury program, immediate tracking data was needed to determine initally and then keep current the capsule present and predicted position for use in controlling critical events as well as for predicting pointing directions for antennas at all the Network stations. Also, real-time information transmitted from the spacecraft through the telemetry system was needed to monitor the physiological condition of the astronaut and the operation of the onboard systems in the capsule. In order to transmit the tracking information to the computing center at Goddard Space Flight Center faithfully, in as near real time as possible, a ground communications network with extreme reliability was a primary requirement. From the launch and recovery standpoints, the launch area was, of course, fixed at Cape Canaveral. An orbital inclination was desired which would place the orbital flight path over generally more inhabited areas which would locate the recovery point after three orbits in a highly instrumented area available to deployment of sea-borne recovery forces. These considerations resulted in an inclination of some 32.5 degrees which placed the reentry trajectory over the heavy instrumentation in the continental United States and the recovery area in the down-range area of Canaveral. Having decided upon an inclination and corresponding launch azimuth, one of our initial goals was to locate ground stations around the Earth so that we could view and contact the capsule five out of every fifteen minutes during the first three orbits. To review how the stations fulfilled specific needs, let us consider the Project Mercury flight path in relation to the network stations as shown on the next slide. (Slide 2) After launch from Cape Canaveral, the first pass occurs over Bermuda. A station at Bermuda was required as an extension of Cape Canaveral to obtain tracking data during the critical launch period when the sustainer engine is cut off, i.e., when insertion into Earth orbit occurs, in order to assure data required to make the critical go no-go decision. In addition, it could transmit commands required should mission abort and early reentry be determined necessary.

A ship was required in the Atlantic Ocean to receive telemetry and for ground-air-ground communications from the spacecraft and to relay information to the control center.

A tracking station was placed on the Grand Canary Island to localize the touchdown point by radar observation in event of abort and early reentry should insertion not be effected. The stations at Kano, Nigeria and at Zanzibar and the ship in the Indian Ocean were required for communications and telemetry. These could cover at least two of the first three orbits.

A tracking and command capability was needed in West Australia to make antipodal observation for refinement of the spacecraft orbit and to remotely reset the on-board timer, if necessary, for initiating retro-rocket firing.

The stations at Woomera, Australia and at Canton Island were needed for telemetry and communications. In addition, the Woomera station could provide tracking on the early passes.

Hawaii was also required to track and have a capability of commanding the retrotimer to back up the West Australia command function.

In event of retrotimer failure and imminent failure of the astronaut to initiate retrofire manually, a station with a command capability was required at Point Arguello on the Pacific Missile Range so that this critical event could be covered on the completion of the second or third orbits. A similar station was required at Guaymas, Mexico for possible termination of the flight on the first orbit.

And finally stations at White Sands, Corpus Christi, and Eglin Air Force Base in Florida were utilized to maintain tracking continuity after retrofire in order to localize the touchdown point during the planned reentry into the primary recovery area in the Atlantic Ocean.

While an attempt was made to meet the basic five-out-of-fifteen minute contact time, the earth's rotation of 45 degrees on its axis during three orbital paths required certain compromises to be made in the total number and location of the stations. These resulted in gaps such as one of approximately 30 minutes on the third orbit.

Another of our goals was to use equipment of prove reliability for the Network stations wherever feasible. The wisdom of this choice, we feel, was demonstrated by the excellent successes of the tracking network in the Mercury program. The next slide (Slide 3) illustrates the equipments installed at each station. All the Manned Space Flight Network stations, except White Sands and Eglin, were equipped for telemetry reception on the standard UHF frequencies. General systems of this type had been used extensively in the past and the techniques and equipment were well known.

All stations were equipped with tracking radars with the exception of the two ships; the two African stations and the Canton Island station. Two types of radars were employed in the network for precision tracking: a long range type operation at the S-Band and the FPS-16 type operating at C-Band. Three key tracking stations were equipped with both types to obtain greater reliability by having a redundant radar tracking capability. At the time of original network planning, only the S-Band type beacons had had an extensive flight history. Consequently it was felt extremely important to include this system in addition to the C-Band transponder required in conjunction with the FPS-16 radars. Thus if one transponder failed, the alternate radar tracking complex could provide the computers with sufficient data to determine the capsule orbit.

The next slide (Slide 4) pictures a typical FPS -16 radar installation. It has a 12-foot diameter parabolic reflecter antenna with a 4-horn monopulse feed system. The characteristics are listed on the next slide (Slide 5). It operates in the frequency range of 5400 to 5900 megacycles per second with a peak power output of 1 megawatt. This radar provides range data with an accuracy of the order of 7 yards at a distance up to 500 nautical miles with a capsule beacon peak power of approximately 400 watts. The S-Band radar has a 10-foot diameter dish and operates near 3000 megacycles.

The next slide (Slide 6) illustrates an antenna installation typical of those used for signal acquisition as well as telemetry reception and capsule communications at each of the sites. It consists of an array of 4 helical elements having a gain of 18 db in the telemetry frequency range of 225 to 260 megacycles. Two of these quad-helix arrays are arranged in height and space diversity through couplers which feed a set of preamplifiers to provide the best signal. The antennas, coupler, and preamps are included in the antenna pedestal shown here.

The Cape Canaveral telemetry site has in addition a 60-foot diameter parabolic antenna which provides 26-db gain and is also used as a VHF communications antenna.

Four standard FM telemetry receivers are required at each site, two for diversity and two for duplication of these for reliability. IRIG standard subcarrier channels 5, 6, 7 and 12 are used with an effective receiver noise bandwidth of 50 kilocycles. For demodulation, there are either 6 or 8 discriminators installed at each site with either a 90 or 15 channel decommutator. In addition, all sites are provided with equipment for post-detection recording of all of the telemetered data, and real-time presentation of selected critical channels of telemetry information.

The ground station and ship instrumentation for the command function also utilized antennas similar to that shown on this slide. In general, each station has three similar antennas: two for telemetry and voice reception, one of which is used as an acquisition aid, and a third antenna for command control and voice transmissions in the 500-mc frequency range. For the command function, two FRW-2 transmitters are installed for redundancy, each having a power output of about 500 watts. The signals are tone-modulated with up to 6 tones. Monitor receivers and decoders are also installed for making a permanent recording of command signaling.

One of the most critical function the world wide network must perform is that of obtaining data and making high-speed near-real-time computations. During a flight, the tracking data from the Manned Space Flight Network stations are sent via ground communications to the Goddard Space Flight Center in Greenbelt, Maryland, for processing. In a moment I'll return to the subject of ground communications. The development of an extensive computer program was required to handle the tracking data and to make critical computations for the so-called "go or no-go" and retrofire and reentry decision within milli-seconds of tracking measurements. At the Goddard Computing Center two IBM 7094 computers are installed. These operate in parallel to accept position data in digital form directly from the stations and perform computations for each of the separate flight phases: the launch phase, the orbital phase, and the re-covery phase.

The Computing Center at Goddard also houses various displays and plot board presentations for visual indication of capsule location, velocity, and status of certain critical capsule systems. In the weeks preceding a flight, the Computing Center was employed to conduct many mock flights using prepared tape data to simulate the operation of the Network. A great familiarity with the use of the Network for mission control was achieved through practice in handling simulated problems. I might add that data from the astronaut and from his reactions were not merely simulated but he was actually placed in the information loop for training.

The job of providing world-wide ground communications to link the network stations required an unusual amount of careful engineering and attention to assure obtaining maximum reliability. T' . communication circuits for transmitting data on Project Mercury are indicat[illegible] ctorially on the next slide (Slide 7). The Goddard Space Flight Center act as the main communication terminal for all of the ground stations in the Manned Space Flight Network. Through this Center the stations are linked to the Computing Center at Goddard and the Mercury Control Center at Cape Canaveral. Ground communications, consisting mainly of leased commercial circuits; include 100,000 miles of teletype circuits, 35,000 miles of telephone lines, and 5,000 miles of high-speed data circuits. Several of the links were duplicated via different routes for reliability. Except for launch phase data, the volume of data from the network stations required the use of 60-word-per-minute teletype circuits around the world. This low rate was possible through use of a technique which I will describe later that involves sending summary messages from the remote stations. Voice communications with all the network stations were controlled from the Mercury Control Center and the Goddard Space Flight Center.

Next we will consider in retrospect the changes made to the Manned Space Flight Network for ground support of the 6-orbit mission of Schirra and the 22-orbit mission of Cooper. The requirements and support for these missions were analyzed but this time with the experience gained on prior operation of the network. We had learned that we could relax the requirement for an average contact of five minutes out of every fifteen minutes of flight to as little as one contact per orbit for some orbits for the following reasons: first, because the network had demonstrated that an orbit could be determined with good accuracy with data from the first orbit; and second, the flight experience of the astronauts dispelled apprehensiveness about physical condition and responsiveness when subjected to launch acceleration, weightlessness and other conditions of space flight that differ from the normal environment of man. Also, there was no question that the astronaut could play an important role in controlling and increasing the reliability of the spacecraft system. Thus there was a decrease in the rate at which contacts were required to at least one contact per orbit, and it was determined that the existing sixteen network stations could meet the requirements of the longer duration missions provided the two ships were judiciously relocated and a command capability was added to the second ship.

For the 6-orbit mission shown on the next slide (Slide 8), the Indian Ocean ship was moved westward to a location nearer South Africa. A ship was no longer located in the Atlantic Ocean but one was stationed in the Pacific near the Philippine Islands as shown. This ship was also required to have the capability of transmitting commands to initiate the retrofire sequence if necessary. For Cooper's 22-orbit 34-hour mission, a ship was not placed near South Africa. Instead a ship was stationed in the South Pacific as shown. Later I will show resulting telemetry contact time obtained with this latter Network configuration.

As a result of the Mercury program's continued need for both a daylight launch and a daylight recovery, the 6-orbit and 22-orbit missions had to have a planned recovery area in the Pacific near Midway Island. However, these missions could have been terminated on orbits 1, 2, 3, or 16 and still have a daylight recovery because the Atlantic area was also maintained. As mentioned previously, it is necessary that a station be in sight of the capsule in the critical area where retrofire is planned to take place. The station can thus communicate with the astronaut and initiate last minute ground commands if necessary. The ship located northeast of the Philippines met these requirements.

With this brief review of the characteristics and physical arrangement of the Manned Space Flight Network, I would like to discuss its actual use in performing mission control. As indicated earlier, a mission was generally divided, in terms of the specific emphasis to which the entire data output of the network was directed, into three phases, namely, (1) the launch phase including the actual go-no-go decision at insertion into orbit, (2) the on-orbit phase, and (3) the reentry and recovery phase.

During the launch phase, there are a number of factors of paramount consideration for mission control: The operation of the booster vehicle, the launch trajectory, the cut-off velocity prediction; and the possible requirement for early mission abort and subsequent astronaut recovery. Each of these factors has special needs which had to be matched by the network program for tracking and computing. Accurate and positive tracking of the vehicle during the entire launch to insertion trajectory is mandatory. During the launch phase, data is obtained from three tracking facilities in the Cape area. These are the FPS-16 radar, the Azusa tracking system, and the launch vehicle radio guidance tracking system. Data from these three tracking systems are converted at the source from analog to digital form at a rate of approximately 10 measurements per second of Azimuth, elevation and range. These data are transmitted in real time to Goddard Space Flight Center and fed into two IBM 7090 computers that operate in parallel to perform computations for the critical go-no-go decision. Simultaneously, these computers continuously predict the impact points of the capsule had there been a requirement for abort of the mission at any time during the launch phase. Computer outputs drive various plotting board presentations, including a specific presentation for the go-no-go decision and for the predicted impact locations. Throughout the entire mission these computers generate pointing information for all the ground tracking stations to allow rapid acquisition of the capsule transmissions as it appears over the local horizon. Since the orbital insertion of the Mercury capsule has to take place at a relatively low elevation angle from the Cape tracking equipments, and since tracking from the Bermuda station is extremely important, redundant radars were installed at this station. In addition to the tracking information transmitted to the Goddard Space Flight Center computers for the main computation, a 709 type computer on Bermuda permited the vital go-no-go decision to be made by this station should difficulties with communications to the Cape have been encountered at this critical time.

The next slide (Slide 9) shows the computed parameters required for determining the go-no-go decision. Flight path angle, designated as gamma, is plotted vertically. Gamma is the angle between the normal to the local vertical and the spacecraft velocity vector, or stated another way, gamma is very nearly the angle between the current direction of flight under thrust and the direction of flight were the spacecraft in circular orbit. On the horizontal scale velocity ratio V over Vr is plotted, where V is the velocity measured by the tracking network and Vr is the velocity required to achieve circular orbital conditions at a given altitude. The trace, of course, is actually continuous, however, it is plotted in three segments, each of which uses different scale units both in the vertical and horizontal to emphasize certain critical portions of the launch trajectory, which accounts for the seeming discontinuity. The parameters of flight path angle and velocity ratio taken into account by this chart are directly indicative of whether the conditions for satisfactory insertion are being met during the launch phase. The shaded area represents the limits of variation of these particular parameters within which a satisfactory orbital insertion can be achieved. If the trace ends inside the shaded area a satisfactory insertion is indicated. If it terminates to the left of the area the spacecraft would not have achieved enough velocity to complete one orbit. To the right, a problem could be expected with heating during reentry.

Plotboards were used to present this critical data at Goddard Computing Center and at the Mercury Control Center at the Cape. The Mission Director at the Cape required information as early as possible in advance of impending flight difficulties. This type of plotboard presentation in a manner of speaking tells what the computers "know" as they continue to recommend a "go" decision for the launch phase. This slide (Slide 10) shows the four plot-boards installed at Goddard. During the launch phase the go-no-go plot is normally presented in duplicate on the two center boards while the remaining boards are used for other selected plots. What is presented on the charts may be selected (Slide 11) at the console shown here in the foreground so as to best match the needs for mission control during each phase of the flight. The Mercury Control Center at Cape Canaveral shown on the next slide (Slide 12) also made use of the Goddard Computing Center data to feed the similar plot-boards shown here to the right of the screen. In addition, during the launch phase telemetry information on the condition of the astronaut and capsule systems was transmitted to the Control Center for observation by the flight controllers at the consoles shown in the center of the control room.

The Network tracking support for the launch phase was not considered complete until the spacecraft velocity vector was determined at insertion and until the initial orbital elements were calculated and transmitted to the Mission Control Center. Once the capsule was satisfactorily inserted in orbit, the primary task of the Network became that of acquiring telemetry and voice data and transmitting it to the Mission Director so that he could monitor aeromedical information on the astronaut and status data on the capsule systems. The astronaut's blood pressure, body temperature, and electrocardiograph data were examples of critical aeromedical data. Information about the capsule's systems which had to be known included readings on the amount of hydrogen peroxide fuel remaining, oxygen pressure, various component temperatures and other similar parameters. To fulfill these needs for each Mercury flight the Network had to acquire and record on magnetic tape a total of approximately 90 channels of telemetry data each time the spacecraft passed within sight of a Network station.

The Network also provided communications circuits, as shown in an earlier slide, to transmit to the Mission Director the information he required to direct successfully a manned Mercury spaceflight. To achieve reliable world-wide communication circuits, the Network was limited to the use of 60 words-per-minute teletype links to stations remote from the U. S. The limitations of this communication capability required, however, that a specially trained team of mission personnel be located at the Network stations to accomplish several tasks: (a) to talk to the astronaut and to monitor and interpret telemetry information directly, (b) to compose concise summary messages based on voice and telemetry information and (c) to send the summary messages to the Mission Director for decision. A selection of approximately 30 quantities of telemetry data of major importance were displayed at consoles at each of the Network stations and at the consoles at the Mercury Control Center. During a mission the flight controllers, as they were called, were situated at the consoles to talk to the astronaut and to observe the telemetered information for malfunctions. A doctor sat at the aeromedical console and usually another astronaut sat at the capsule communications console. In addition, a communications technician was also present along with other technical experts.

This next slide (Slide 13) illustrates a view inside the station on the Grand Canaries. The flight controllers sit at the consoles in the background. This close-up view on the next slide (Slide 14) shows the instrumentation at a typical remote site for the aeromedical console, the capsule communication console and the capsule observer console. This station may have been fore-warned of the immediate need for special data such as suit temperature. This type of data and other important information, including trends in readings such as inverter temperature changes, were sent immediately to the Mercury Control Center via voice or teletype. Normally, however, a summary report consisting of a compilation of the reports from each of the flight controllers was transmitted to the Cape after each pass. Established procedures required that the flight controllers refrain from all action indicated necessary until instructions were received from Mercury Control. Reliability in Network communications thus required extreme attention because the astronauts' safety could have been fatally dependent upon effective real-time communications.

During the orbital phase the Mission Director also had to know the precise position of the spacecraft at all times so as to carry on the flight program and make decisions concerning the time and place for reentry. Tracking was accomplished by the station radars operating in the beacon mode. When the capsule was in sight of a station, a set of measurements of azimuth, elevation, and range were made once every 6 seconds instead of 10 sets of measurements per second as required during the launch phase. Orbital tracking data was also transmitted via teletype to the Goddard Computing Center in near real time as the capsule passed each successive station. The Computing Center then up-dated its orbital elements, starting with the interim elements determined from data obtained during the first pass over Bermuda. The Center in turn computed and provided pointing data to the Network stations not yet reached by the capsule until the completion of the flight.

In order to terminate the orbital phase of the mission with a satisfactory reentry and recovery of the capsule and its occupant, the precise time for retrofire had to be computed during the orbital phase before the necessary commands could be transmitted to the capsule. In addition, tracking of the reentry trajectory was required so that the precise landing area could be predicted as closely as possible. The Network accomplished the retro timing requirement by combining orbital computations with a program of curve-fitting of predicted reentry trajectory computations to compute the time to initiate retrofire sequence. The entire retrofire sequence was accomplished either manually, by verbal contact through Network communications with the astronaut, or automatically by Network ground command. The commands would preset a clock in the capsule which triggered the sequence. When updating of the orbital elements affected timing computations, the retro-clock timing was reset on the next station pass affording the opportunity. Had there been a failure in the retro-timer, firing of retro-rockets was possible by direct command from the Network stations.

Tracking during reentry for recovery in the Atlantic Ocean was accomplished on the first three orbits with relatively full radar coverage provided by the Network stations across the southern portion of the U. S. For reentry in the Midway area, the Departmen   Defense provided a tracking ship to accomplish reentry tracking in the Pacific recovery area. Data from these stations were transmitted in near real-time to the Computing Center and were used continuously to refine the impact point predictions and drive the plot-boards at the Centers. With these predictions, the Mission Director could advise the recovery team of the predicted impact location to an accuracy of several miles.

Now that we have described how the Network was utilized during the actual missions, the logical question is how well did the Network perform during these flights?

This next slide (Slide 15) summarizes the actual performance obtained with the Manned Space Flight Network for the Mercury program. Some of you can recall several years ago how unduly optimistic these figures would have appeared for predicted performance of the Manned Space Flight Network. In considering performance as a whole, one can say the Network performed one-and-a-half to two times better than originally anticipated. It should be noted that the "Network Communications" and "Computer Reliability" performances shown on this slide were achieved partly due to the use of backup facilities previously mentioned. Now I would like to discuss briefly the orbit computations and telemetry data acquisition performance.

The performance of the Network in terms of its accuracy in determining orbits was a vital measure of its usefulness in performing mission control. The most demanding task which the Network computers had was that of establishing an initial orbit with sufficient accuracy for a go no-go decision using data obtained only from tracking equipments in the Cape area and the down-range station at Bermuda. The next slide (Slide 16) shows, for each orbital flight, how apogee and perigee, calculated only on the basis of data from its first pass over Bermuda, compared with the apogee and perigee that was calculated after the spacecraft had made its initial pass over Australia, approximately one-half orbit later. In every case there has been less than 1.5% change. Here the effectiveness of radar measurement for trajectory computations was demonstrated and provided the assurance we were looking for in its use particularly for the longer duration missions with decreased coverage.

It is interesting to note that when calculating the retro-timer clock setting for the MA-9 mission for possible reentry after three orbits, there was a difference of only 2 to 3 seconds between the setting obtained using first pass data for computations and that including the Woomera data. This difference would be equivalent to an impact prediction error of 12 to 18 miles.

The main factors contributing to inaccuracy of the final results in orbital calculations have been geodetic uncertainties and the lack of a common, well-known datum for the tracking radars. Knowledge of these uncertainties have improved since the initial John Glenn flight and the accuracy of the Manned Space Flight Network orbital determinations has improved concurrently to the point where spacecraft position in space can be determined to the order of 200 to 300 yards.

Performance of the Network with regard to its telemetry function could also be described as excellent. In fact, during the entire Mercury program, there were no telemetry data failures. Relatively good telemetry coverage was provided for the first three orbits. This performance was, of course, duplicated for orbits 16, 17 and 18. Usually a signal was acquired as the capsule approached to approximately one degree below its line of sight view from a station. Calibration of the telemetry data was accomplished both before and during each flight, and there were no unexpected difficulties in the calibration or accuracy of recorded data. This next slide (Slide 17) shows in bar graph form the total telemetry recording time accumulated for each of the orbits in the Cooper flight. The numbers above the bars indicate how many stations recorded during each orbit. As you can observe, the desired Network capability of contacting the capsule at least once per orbit was achieved.

Today I have tried to impart to you a feeling of what was involved in achieving the level of technical support just described. In summary, the Manned Space Flight Network involved extremely careful and detailed planning by a single NASA group familiar not only with tracking and data acquisition facilities but also with the mission characteristics and the requirements for operational control. Further it involved very conservative equipment design. It literally involved months of flight simulations. It involved very careful maintenance and control of change procedures. It involved the development of unique operational techniques. It involved continuous monitoring of the communication lines between the stations to ensure reliable operation. And lastely, it involved continuous training and cross-training of the personnel at each of the stations to develop a high level of operator competence.

With these factors in mind I would like to conclude with a word about the Network changes or, perhaps more descriptively, the Network augmentations planned and underway for support of the upcoming Gemini program.

As you know, Gemini will fly two men for extended periods, up to several weeks, and demonstrate rendezvous techniques through use of a separately launched Agena spacecraft. From the experience gained on the

Mercury program, the Office of Tracking and Data Acquisition began planning early for the ground support of Gemini using the following guidelines: (a), we would make maximum practical use of existing Network facilities to utilize these proven systems and to lower the costs for development and qualification of the ground instrumentation, and (b), we would augment the Network for Gemini at a minimum number of stations using a building block approach so that the cost of expansion to meet future requirements could in turn also be minimized.

There are four general types of requirements (Slide 18) for Gemini which were different from the Mercury program, thereby differentiating what is needed for mission control of Gemini from that which the Network was already capable of providing. These new requirements are shown here.

To facilitate the accomplishment of rendezvous of the Titan II launched manned Gemini capsule with a previously launched unmanned Agena target, orbital changes are required both as a result of a variable launch azimuth and maneuvers affecting orbital elements. The launch azimuth may be set at the time of launch anywhere between 76° and 106°, depending on computations involving time-of-launch relationship with the Agena orbital vehicle. The mission requirement for a variable launch azimuth will be supported by the addition of only one new Network station being installed in northwest Australia. This station will replace the Australian stations both at Woomera and Muchea because of its better location in relation to the Gemini flight path near the antipodal points for the first few orbits.

With the Agena spacecraft and the Gemini spacecraft in orbit, simultaneous tracking, data acquisition, and command will be required. This next slide (Slide 19) shows how existing Network facilities are being augmented to support the Gemini program. All of the stations which have supported the Mercury program are listed plus the new station at Carnarvon. Woomera and Muchea are omitted. Eight locations will be heavily instrumented to serve as "primary" stations. The additional equipment now going into the primary stations consists of new PCM type telemetry equipment and augmentation of the existing tone command system with a digitally coded command capability. The secondary stations will complement the Network by providing additional tracking and communication coverage.

The primary station locations are shown here (Slide 20) in relation to the maximum inclination angle planned for Gemini as represented by the shaded band between $\pm$ 34° latitude. As you may recall, the inclination for each of the Mercury shots was fixed at approximately 32.5°.

The two ships planned here will be the same ships which were used for Mercury.

To handle the larger amount of telemetry data needed for mission control, the eight primary stations will use PCM telemetry equipment instead of FM as used for Mercury. PCM telemetry, or digital telemetry as it sometimes is called, is required for several reasons.

(a) It will match the spacecraft telemetry instrumentation. Much of the on-board data is of an "either-or" nature which is most efficiently handled in a digital format.

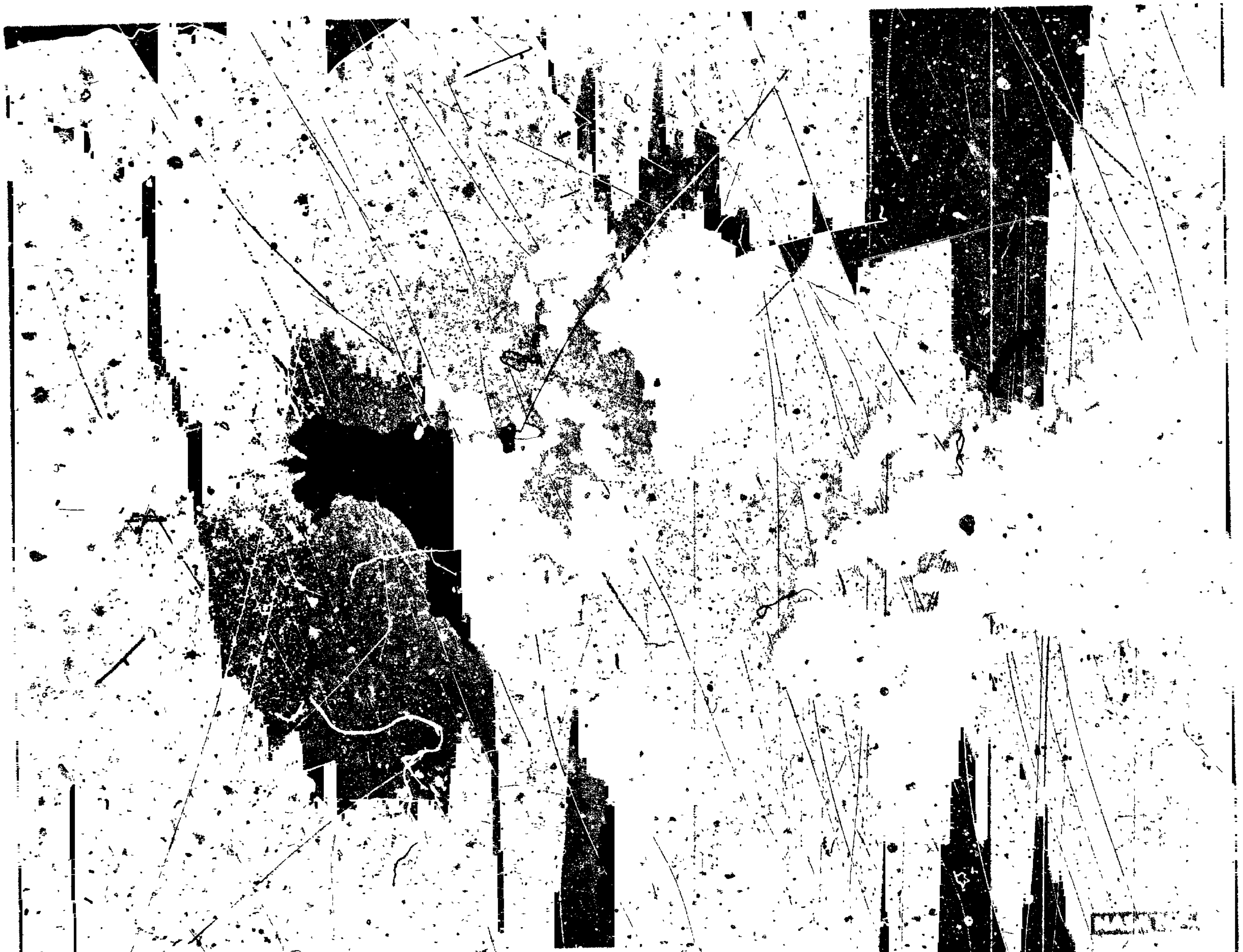
(b) PCM telemetry offers more flexibility in the handling of large quantities of data and is more adaptable to automatic data processing which will be necessary for Gemini.

Ground communications among the stations will continue to be limited in some cases to 60 word-per-minute teletype and the technique of sending summary messages will again be required. However, unlike the Mercury procedures, PCM telemetry will enable the mission controllers at Network stations to use a high degree of automation in processing summary messages to free their time for observation of data as the spacecraft passes overhead. And finally, the need of the project for spacecraft in-orbit control and command will place new requirements on the up-data link and ground communications.

Central control of Gemini operations, including the Agena orientation and propulsion maneuvers, will be initiated from the IMCC (Integrated Mission Control Center) at Houston, Texas by ground command.

To perform the command function we are installing a new digital command system which will use existing FRW-2 transmitters and will receive, store and transmit both real-time and stored command data to the two spacecraft. Part of the command function will be the transmission of data for the on-board velocimeter and of course to up-date the timing of critical orientation and propulsion functions. The digital command system will also serve as a back-up boost phase guidance link if required.

In summary, while certain equipment augmentations will be effected, many of the techniques learned during the Mercury program, particularly in terms of procedures required to assure positive Network support, w[illegible] utilized in Gemini and in this way, an ever-increasing b[illegible]ound of know-how will be available for the extremely comple[illegible]ons which will be encountered in the manned lunar [illegible]gram shortly to be upon us.



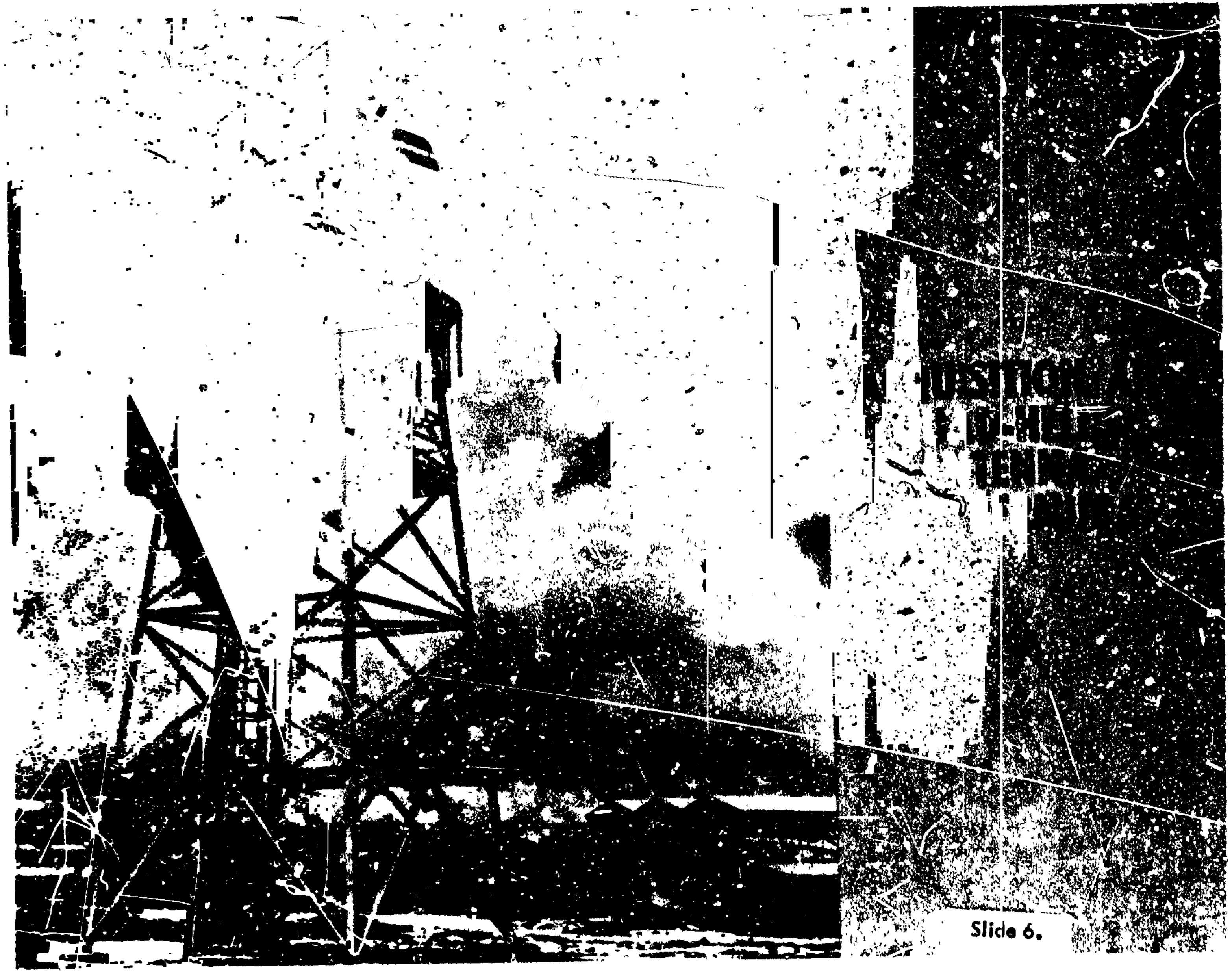
Slide 1.

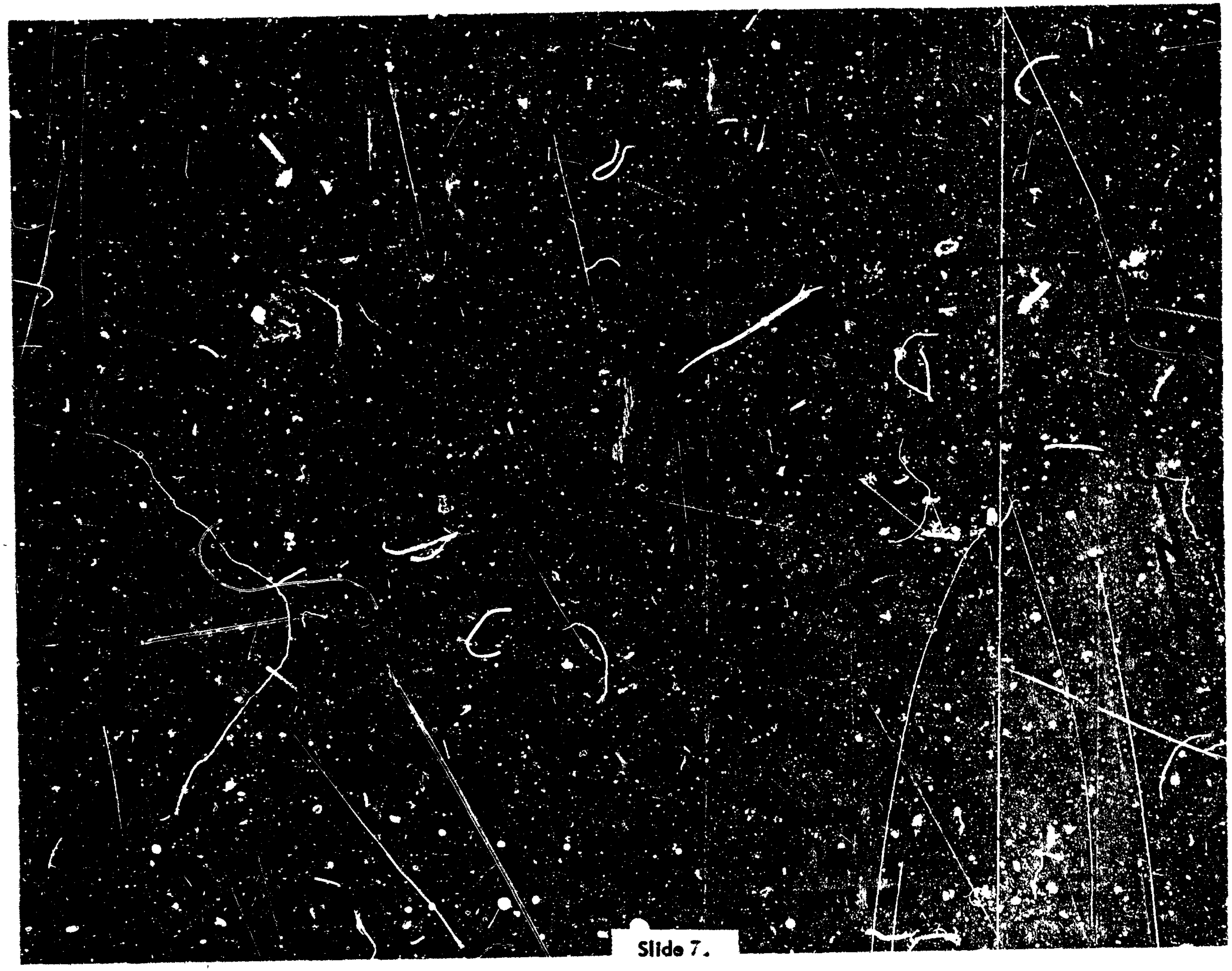

Slide 2.

Slide 3.

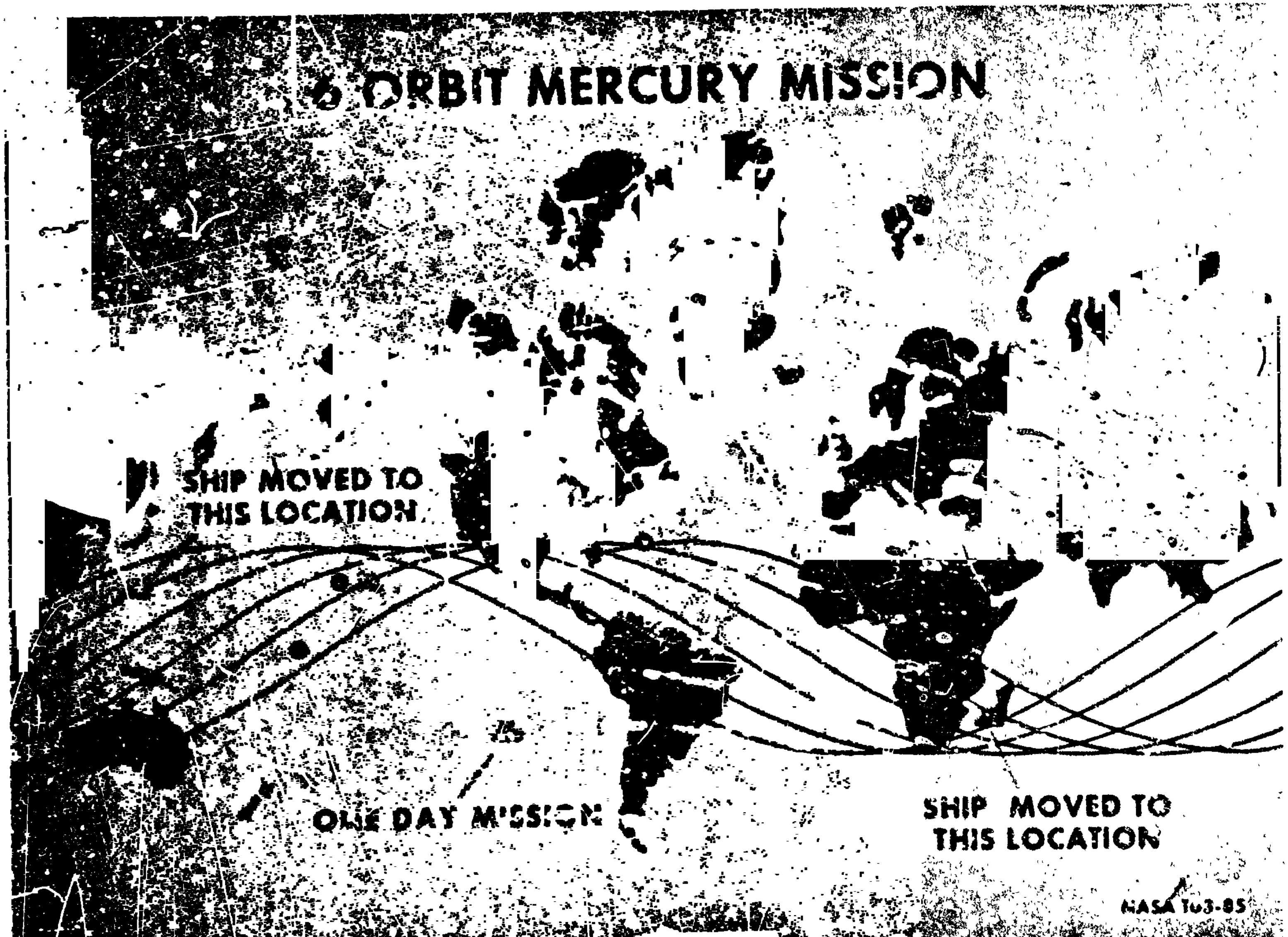
Slide 4.

Slide 5.

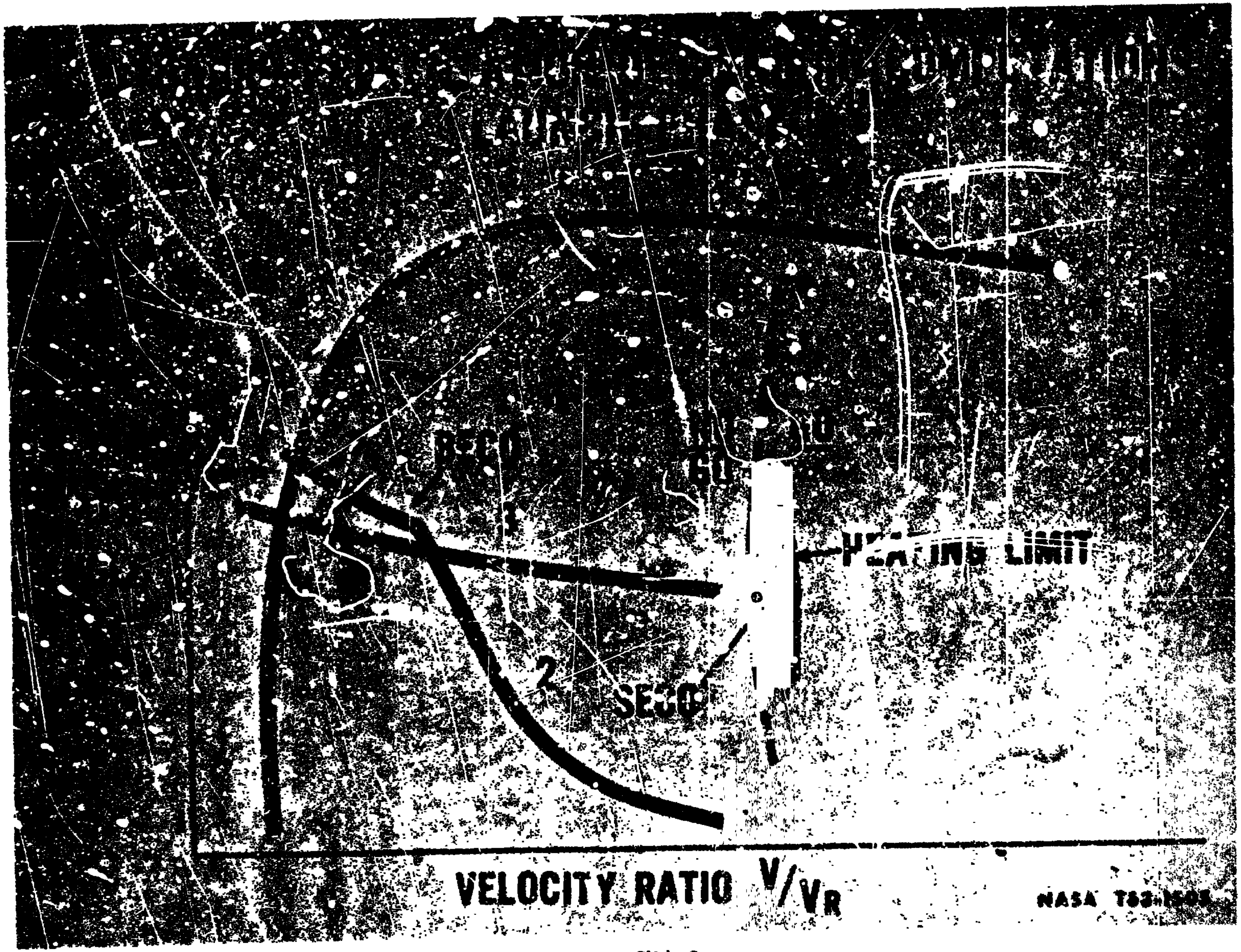

Slide 6.



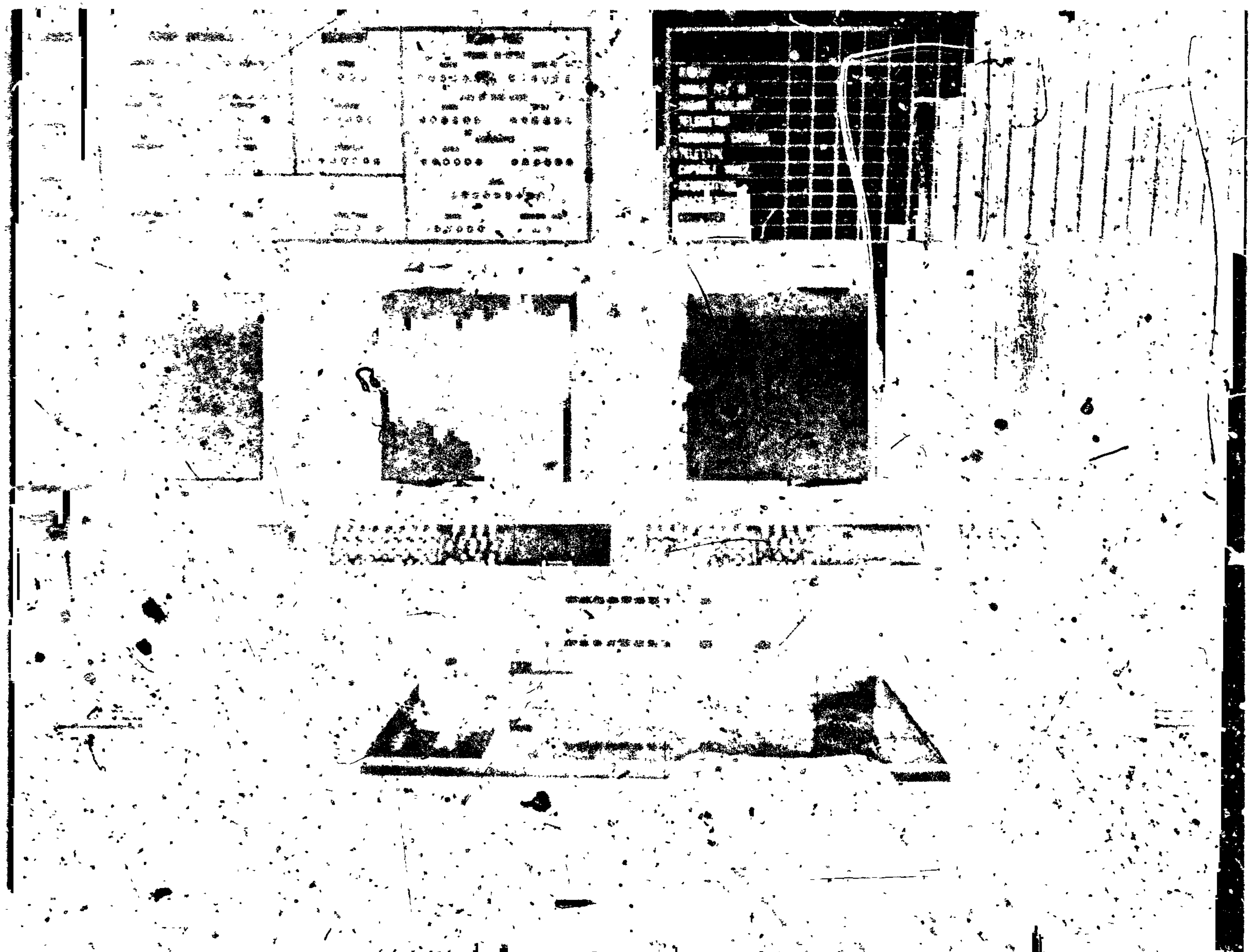
Slide 7.


6 ORBIT MERCURY MISSION
SHIP MOVED TO
THIS LOCATION
ONE DAY MISSION
SHIP MOVED TO
THIS LOCATION
NASA

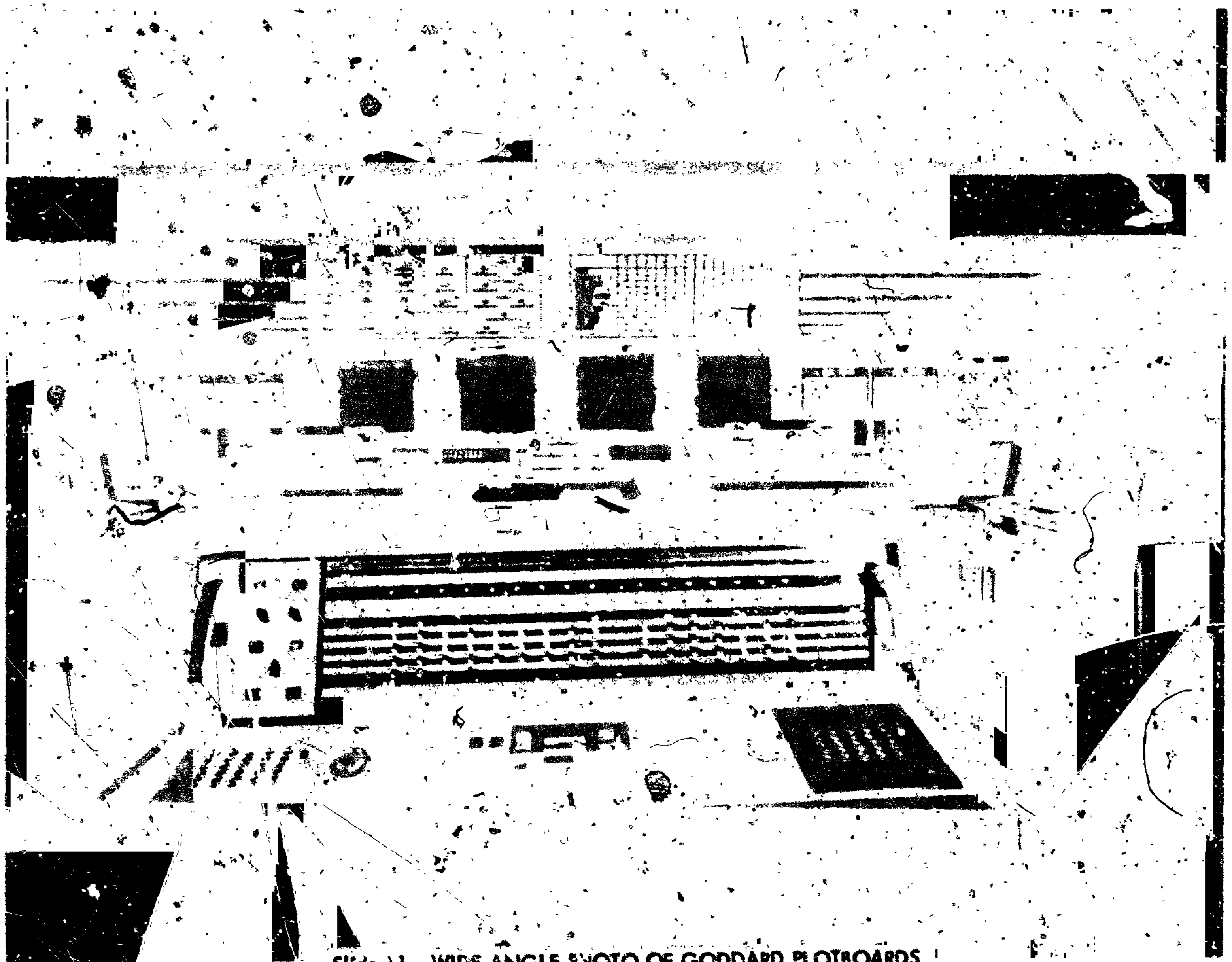
Slide 8.



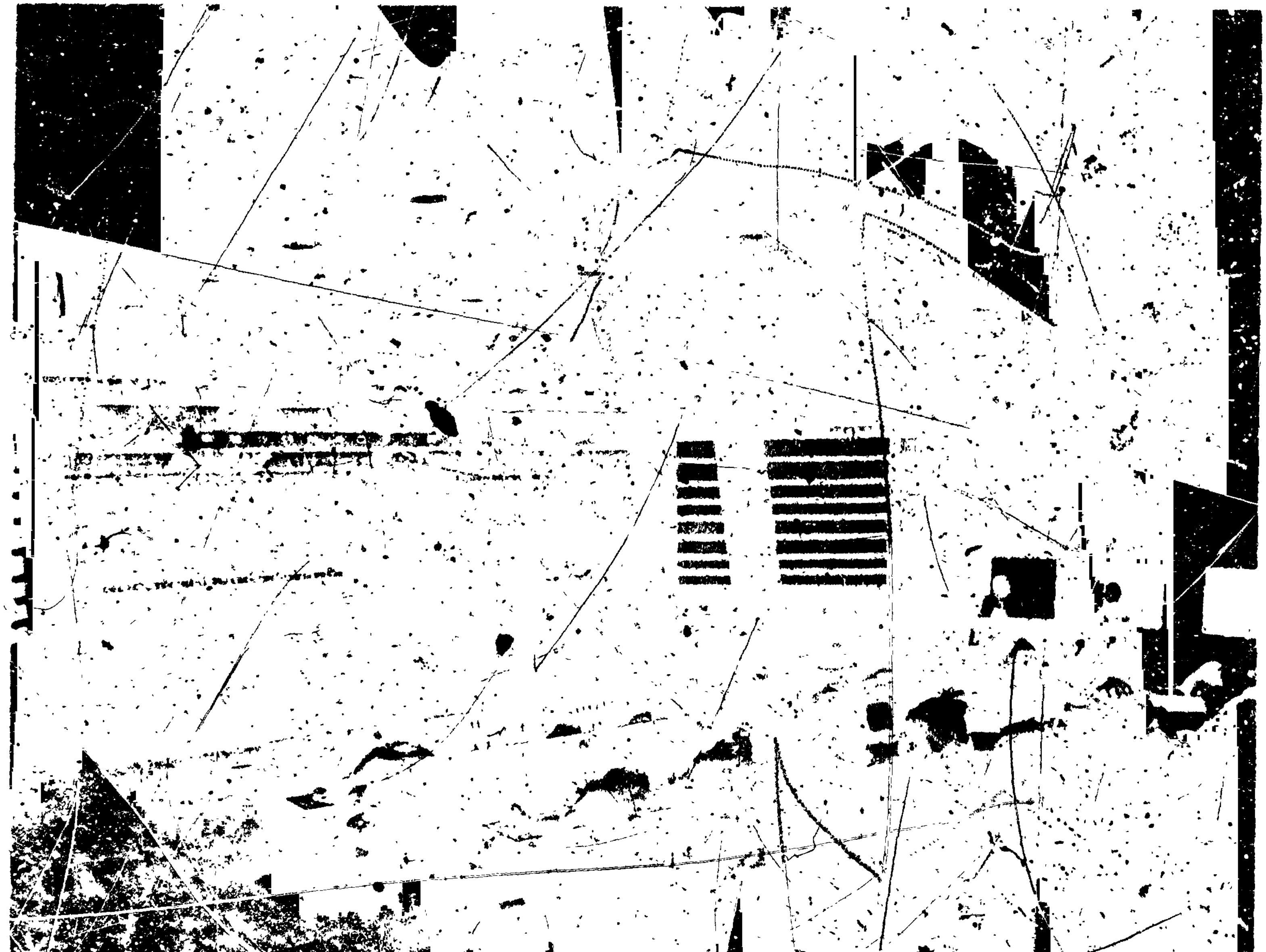
Slide 9.



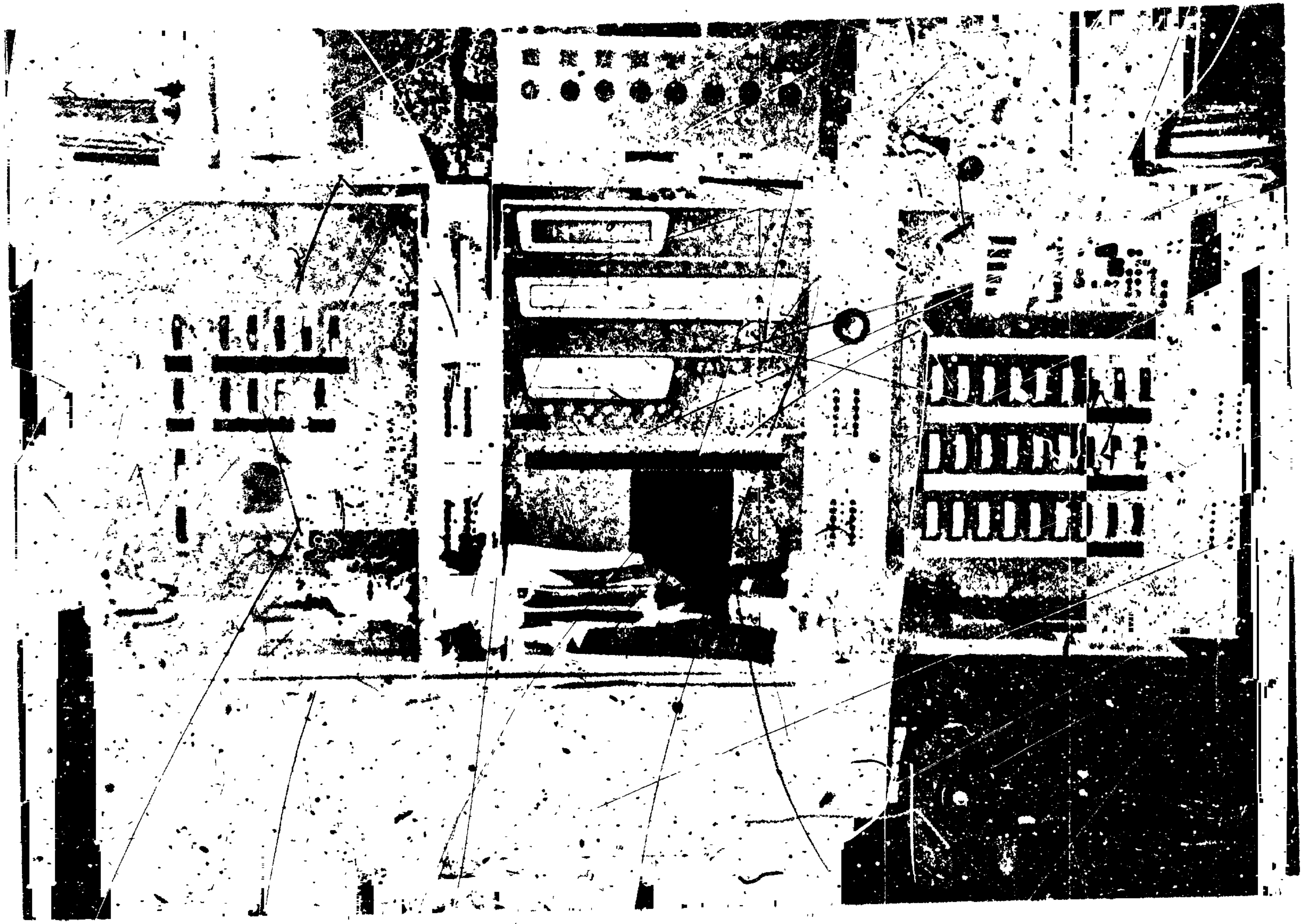
Slide 10. GODDARD PLOTBOARDS



Slide 11. WIDE ANGLE PHOTO OF GODDARD PLOTBOARDS

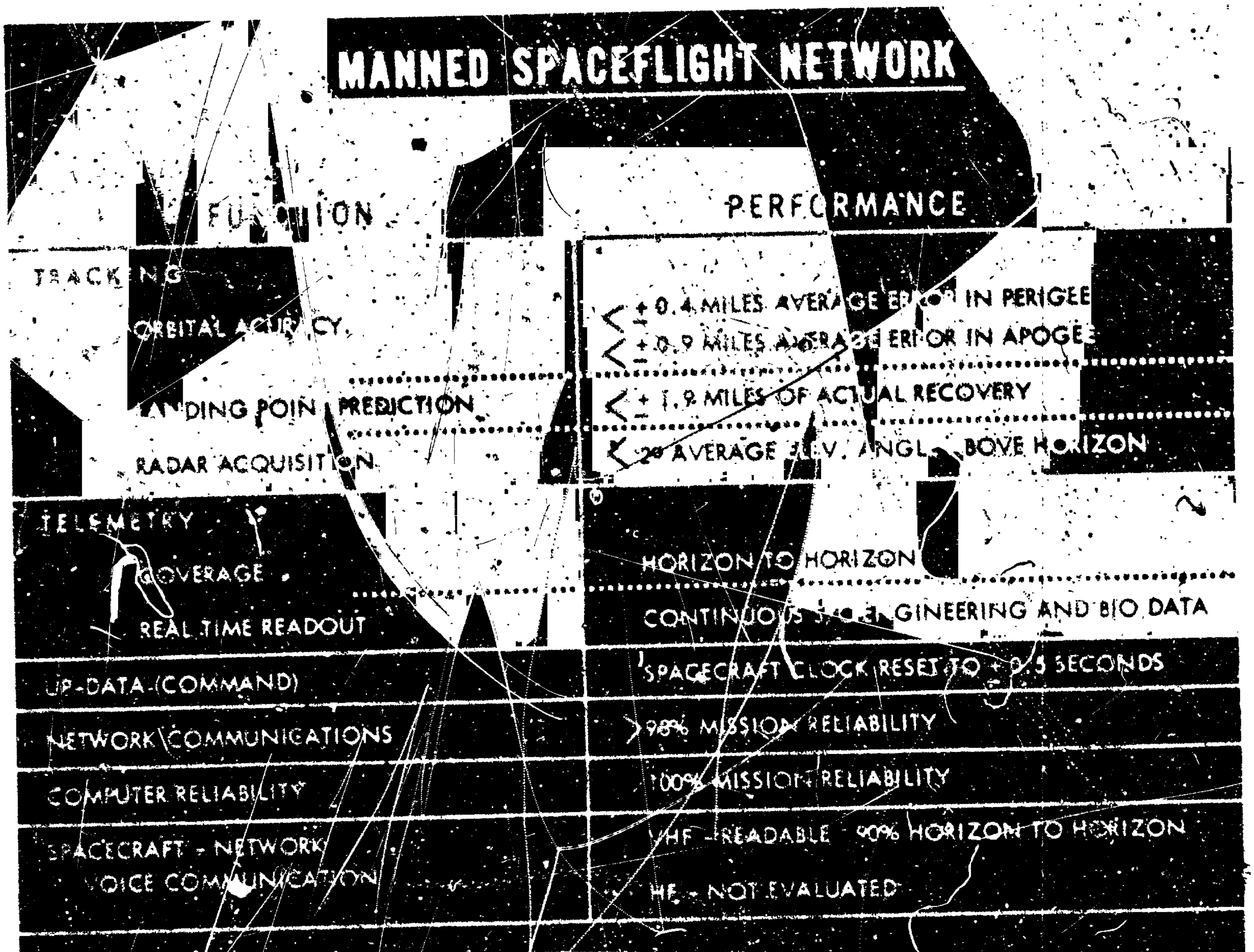


Slide 12. WIDE ANGLE PHOTO INSIDE THE MISSION CONTROL CENTER

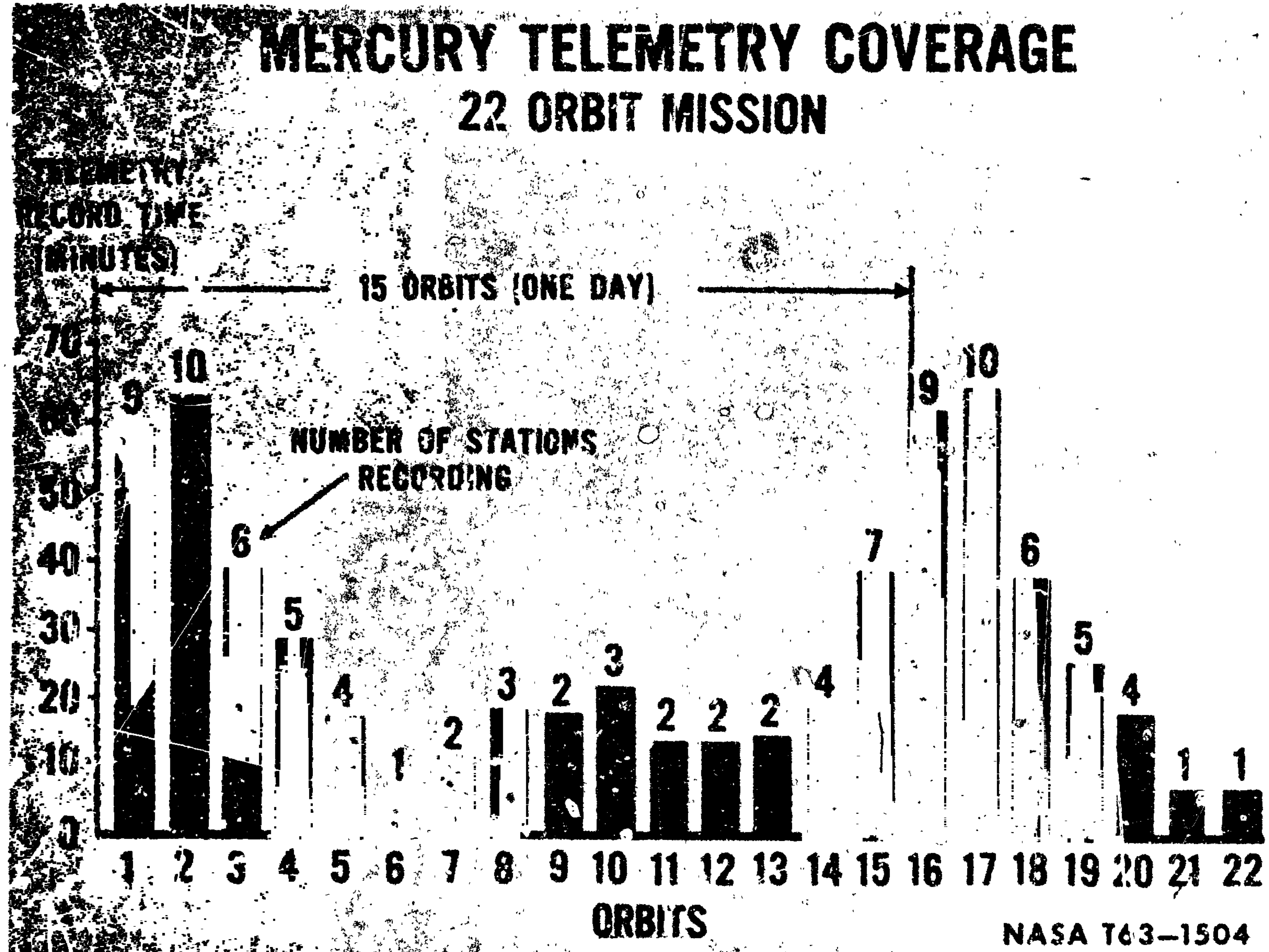


Slide 13. INSIDE ST .TION AT GRAND CAÑARIES

Slide 14. CONSOLE PANELS AT GRAND CANARIES


MANNED SPACEFLIGHT NETWORK
FUNCTION
PERFORMANCE
TRACKING
ORBITAL ACURACY
< ± 0.4 MILES AVERAGE ERROR IN PERIGEE
< ± 0.9 MILES AVERAGE ERROR IN APOGEE
LANDING POINT PREDICTION
< ± 1.9 MILES OF ACTUAL RECOVERY
RADAR ACQUISITION
< 2° AVERAGE ELEV. ANGLE ABOVE HORIZON
TELEMETRY
COVERAGE
HORIZON TO HORIZON
REAL TIME READOUT
CONTINUOUS S/C ENGINEERING AND BIO DATA
UP-DATA (COMMAND)
SPACECRAFT CLOCK RESET TO ± 0.5 SECONDS
NETWORK COMMUNICATIONS
> 98% MISSION RELIABILITY
COMPUTER RELIABILITY
100% MISSION RELIABILITY
SPACECRAFT - NETWORK VOICE COMMUNICATION
VHF - READABLE 90% HORIZON TO HORIZON
HF - NOT EVALUATED
Slide 15.

Slide 16.


MERCURY TELEMETRY COVERAGE
22 ORBIT MISSION
RECORD TIME
(MINUTES)
15 ORBITS (ONE DAY)
NUMBER OF STATIONS RECORDING
70
50
40
30
20
10
0
9
10
6
5
4
1
2
3
2
3
2
2
2
4
7
9
10
6
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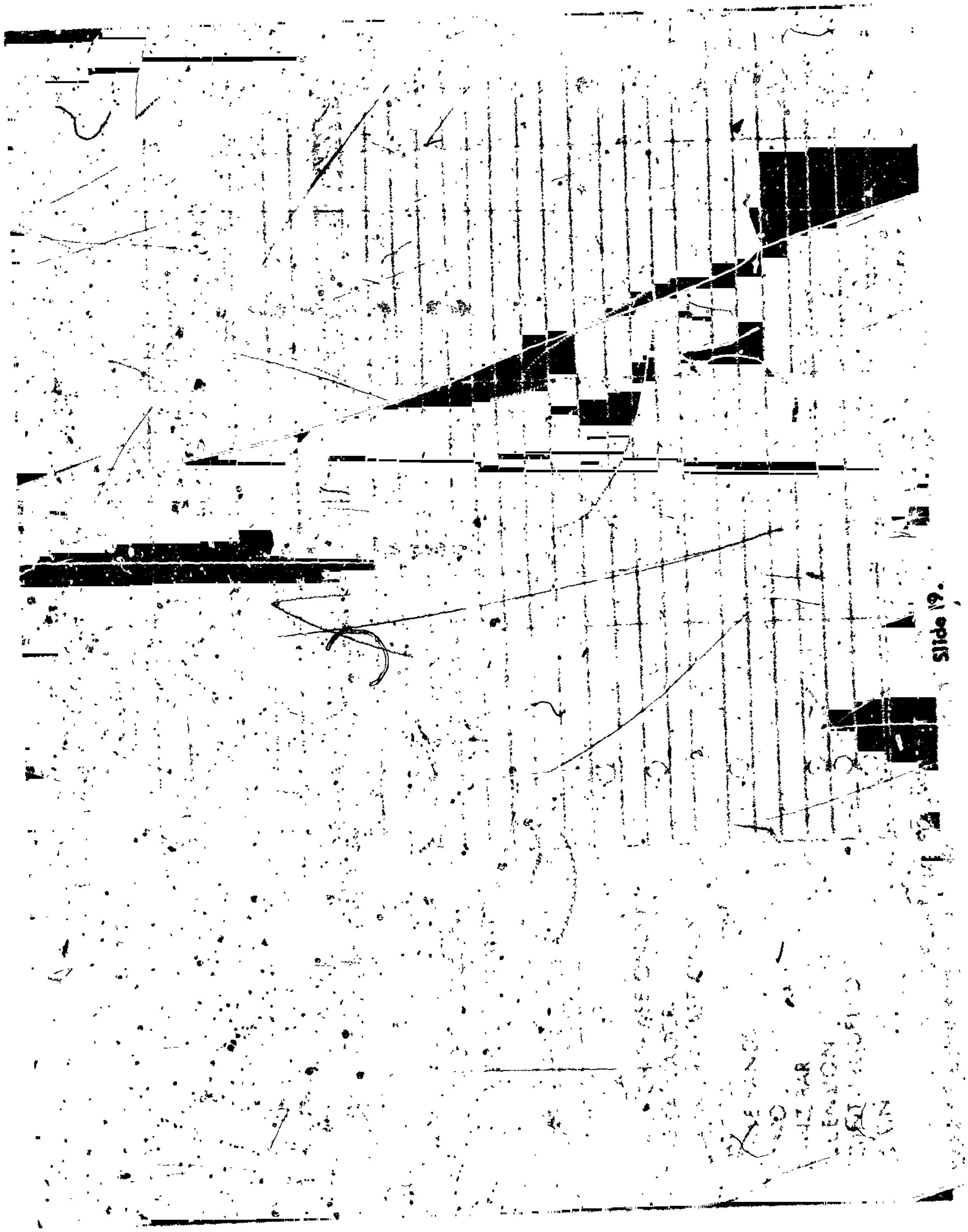
4
1
1
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22
ORBITS
NASA T63-1504
Slide 17.

MANNED SPACEFLIGHT NETWORK

NEW REQUIREMENTS FOR GEMINI

- TRAJECTORY CHANGES
  - VARIABLE LAUNCH AZIMUTH
  - ORBITAL INCLINATIONS $28^{o} - 34^{o}$
- TWO SPACECRAFT
- DIGITAL TELEMETRY
- SPACECRAFT [illegible] CONTROL [illegible] FROM EARTH

Slide 18.



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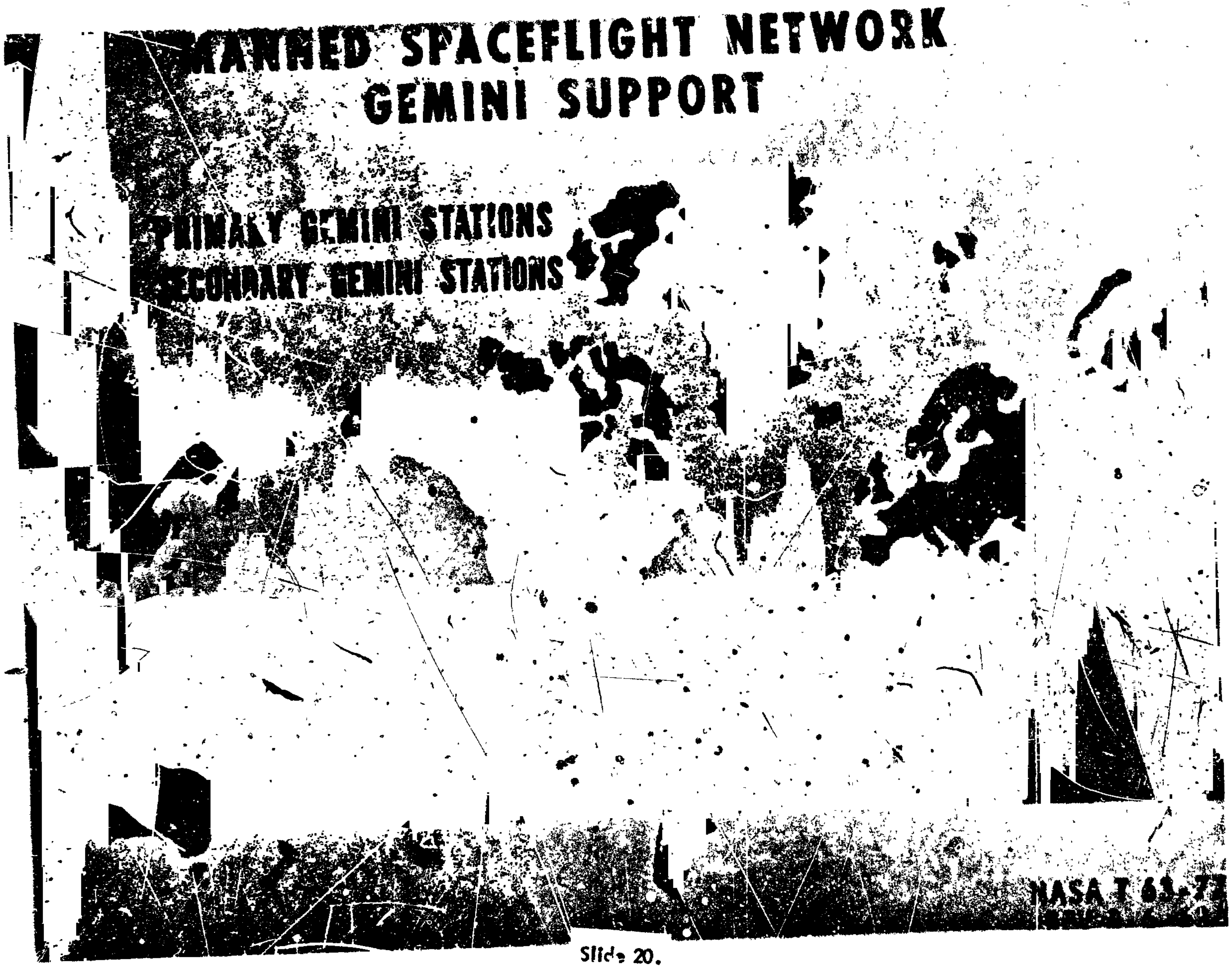
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A REVIEW OF KNOWLEDGE ACQUIRED FROM

THE FIRST MANNED SATELLITE PROGRAM

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A REVIEW OF KNOWLEDGE ACQUIRED FROM

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SYNOPSIS

With the completion of the Mercury program, science has gained considerable new knowledge about space. In more than 52 hours of manned flight, the information brought back has changed many ideas about space flight. Design problem occupied the first and major portion of the Mercury program. The heat shield, the shape of the Mercury spacecraft, the spacecraft systems, and the recovery devices were developed. Flight operations procedures were organized and developed and a training program for both ground and flight crew followed. Scientific experiments were planned with man in the loop. These included photography, extra spacecraft experiments, and observation or self-performing types of experiments.

But the real knowledge of Mercury lies in the change of the basic philosophy of the program. At the beginning, the capabilities of man were not known, so the systems had to be designed to function automatically. But with the addition of man to the loop, this philosophy changed 180 degrees since primary success of the mission depended on man backing up automatic equipment that could fail.

INTRODUCTION

As the first manned space flight project of the United States, Project Mercury in its various aspects has been discussed in great detail by almost all members of the project. The purpose of my discussion today will not be to repeat the technical details of Project Mercury, but to outline and discuss some of the significant contributions the program has made to the area of space technology.

It is important to note that 52 hours of manned orbital flight, and less than five hours of unmanned orbital flight by the Mercury spacecraft have produced a large book of new knowledge. The hours spent on the ground development and training, the preparations for flights, and the ballistic flights cannot be calculated, but it contributed heavily to the knowledge we ultimately gained in space flight.

The three basic aims of Project Mercury were accomplished less than five years from the start of the program. The first U.S. manned space flight program was designed to (1) put a man into earth orbit (2) observe his reactions to the space environment and (3) bring him back to earth safely at a point where he could be readily recovered. All of these objectives have been accomplished, and some have produced more information than we expected to receive from conducting the experiment.

The whole Mercury project may be considered an experiment, in a certain sense. We were testing the ability of a man and machine to perform in a controlled, but not completely known environment.

The control, of course, came from the launch vehicle used and the spacecraft systems included in the vehicle. Although we knew the general conditions of space at Atlas insertion altitudes, we did not know how the specific environment would affect the spacecraft and man. Such conditions as vacuum, weightlessness, heat, cold, and radiation were question marks on the number scale. There were also many extraneous unknowns which would not affect the immediate mission but would have to be considered in future flights. Such things as visibility of objects, the airglow layer, observation of ground lights and landmarks, and atmospheric drag effects were important for future reference.

The program had to start with a series of design experiments. We had little criteria for the space vehicle. If we could find that a certain type of heat shield could make a successful reentry and a certain shape of spacecraft, we would have the basis for further design of systems.

A series of flight tests and wind tunnel tests were conducted to get the answers to some of the basic questions. First, would the ablation principle work in our application? Could we conduct heat away from the spacecraft body by melting the fiberglass and resin material? How thick would the shield have to be for our particular conditions? What temperatures would be encountered and for what time period would they exist? Early wind tunnel tests proved in theory that the saucer shaped shield would protect the rest of the spacecraft from heat damage. The flight test on the heat shield must prove the theory. In February 1961 we made a ballistic flight in which the spacecraft reentered at a sharper angle than programmed and the heat shield was subjected to greater than normal heating. The test proved the heat shield material to be more than adequate.

The Mercury spacecraft did not start with the familiar bell shape. It went though a series of design changes and wind tunnel tests before the optimum shape was chosen. The blunt shape had proven best for the nose cone reentry. Its only drawback was the lack of stability. We next tried the cone shaped spacecraft, but wind tunnel testing proved that heating on the afterbody would be too severe, although the craft was very stable in reentry. After two more trial shapes, the blunt bottom cylinder on a cone shape came into being. It was a complete cycle from the early concepts of manned spacecraft, but it was only the first of a series of changes in our way of thinking of the flight program and its elements.

A second part of design philosophy thinking came in connection with the use of aircraft equipment in a spacecraft. We had stated at the start of the program that Mercury would use as much as possible the existing technology and off-the-shelf items in the design of the manned spacecraft. But in many cases, off-the-shelf equipment would just not do the job. Systems in space are exposed to conditions that do not exist for aircraft within the envelope of the atmosphere. Near absolute vacuum, weightlessness and extremes of temperatures makes equipment react differently than it does in aircraft. We had to test equipment in advance in the environment in which it was going to be used. It produced an altered concept in constructing and testing a spacecraft. Although aircraft philosophy could be adapted, in many cases, aircraft parts could not perform in a spacecraft.

The third part of the design philosophy, and perhaps the most important one in regard to future systems is the automatic systems contained in the Mercury spacecraft. When the project started, we had no definitive information on how man would react in the spacecraft system. To insure that we returned the spacecraft to earth as planned, the critical functions would have to be automatic. The control system would keep the spacecraft stabilized at precisely thirty four degrees above the horizontal. The retrorockets would be fired by an automatic sequence under a programmed or ground command. The drogue and main parachutes would deploy when a barostat inside the spacecraft indicated that the correct altitudes had been reached. The Mercury vehicle was a highly automatic system and the man essentially was riding along as a passanger, an observer. At all costs, we had to make sure that the systems worked.

But we have been able to take advantage of man's capability in space. It started from the first manned orbital flights. When some of the thrusters became inoperative on John Glenn's flight, he was able to assume manual control of the spacecraft in order to fly the full three orbits planned in the mission. When a signal on the ground indicated the heat shield had deployed, Glenn bypassed certain parts of the retrosequence manually and retained the retropack after it had fired. In this way, he insured that the heat shield would stay in place during reentry and the spacecraft would not be destroyed by excessive heating. When oscillations built up during reentry, Glenn utilized his manual capability to provide damping using both the manual and fly-by-wire thrusters. The pilot's role in manned space flight was assuming a more important aspect.

Carpenter's flight again emphasized the ability of the pilot to control the spacecraft through the critical reentry period. Excess fuel was used in both of these orbital flights. Schirra's task was to determine if man in the machine could conserve fuel for a long flight by turning off all systems in drifting flight. It was a task that could not be accomplished by a piece of automatic equipment in the confined area of the Mercury spacecraft. Schirra also was able to exercise another type of pilot control. It was the fine control necessary to adjust pressure suit air temperature to produce a workable environment. When we flew the mechanical man in MA-4, we did not have the capability of making fine suit temperature adjustments or to realize the problems we might encounter in suit design. Man could analyze and correct suit temperature, thus pointing out necessary design parameters to follow in future programs.

The MA-4 and MA-5 flights were probably the most difficult of the orbital missions. They had to be flown using only one automatic control system. We had no man along with the ability to override or correct malfunctions in the systems. One of the flights ended prematurely due to malfunctions that we could not correct from the ground. In both cases, a man could have assumed manual control and continued the flight for the full number of orbits. It is no hypothesis or theory, it has been borne out by facts. With this design criteria in mind, the Cooper flight was a fitting climax to the Mercury program. Not only did it yield new information for other spacecraft programs, but it demonstrated that man had a unique capability to rescue a mission that would not have been successfully completed with the automatic equipment provided.

Man serves many purposes in the orbiting spacecraft. Not only is he an observer, he provides a redundancy not obtainable by other means, he can conduct scientific experiments, and he can discover phenomenon not seen by automatic equipment.

But most important is the redundancy, the ability of another system to take over the mission if the primary system fails. Duplicate systems are designed to prevent bottlenecks in the operation of the systems. The single point failure caused the false heat shield signal in Glenn's flight. After the mission was successfully completed, we conducted an intense design review to see if there were any more of these single points in the spacecraft that needed redundancy of design for safe operation. We found many areas where the failure of one component could trigger a whole series of unfavorable reactions. This type of problem had been brought about by the design philosophy originally conceived because of the lack of knowledge of man's capability in a space environment.

The Mercury program taught us not to stack the components on top of each other. It forces limited access, and the failure of one component during checkout makes it necessary to pull out other functioning systems to replace the malfunctioning part. For instance, in the MA-6 flight the short life carbon dioxide absorber in the environmental control system had to be replaced since checkout took longer than had been planned. This replacement required eight major equipment removals and four revalidations of unrelated subsystems for a total delay of 12 hours. All of these problems of course resulted from weight and space constraints brought about by payload limitations.

For the Gemini and Apollo spacecraft, the equipment will be modular and replaceable, allowing the substitution of alternate parts without tearing out whole subsystems.

We depend quite a bit on the automatic systems for retrosequence but man has proven that he can and does play an important role in the reentry process. The only manned flight in which the automatic system for reentry was used completely was at the end of Walter Schirra's six orbits. In all other flights, the astronaut took over and performed at least one part of the reentry manually because of some malfunction which had occurred during the flight.

As we move into the Gemini and Apollo programs, a maneuvering capability has been built into the spacecraft to allow changes in flight path both while in orbit and during reentry into the atmosphere.

The ΔV or translation engines provided will allow modifications to the orbit for rendezvous with other vehicles in orbit. Also, by use of an offset center of gravity, the spacecrafts will have an L/D capability not provided in the Mercury vehicle. This will allow the onboard computers to select a particular landing point at any time during the flight and after retrofire or atmospheric reentry the vehicle can be maneuvered within a given footprint to reach this desired landing area. The astronauts will provide the necessary back-up to these complex systems and can at any time assume manual control of the system so that a proper and safe landing can be assured.

Our experience with the Mercury network changed our thinking about the operation of this worldwide tracking system for manned flights. In the initial design of the network, we did not have voice communication to all the remote sites.

But we soon found that in order to establish our real time requirement for evaluating unusual situations, we needed the voice link. When we started the program, the determination of the orbital ephemeris was a process that could take several orbits to establish. We could not tolerate such a condition in a manned flight so we set up a worldwide network which would maintain contact with the astronaut approximately 40 minutes out of every hour. But continuous voice contact with the astronaut has proven unnecessary and in many cases undesirable. While we retain the capability to contact an astronaut quickly, we have tried to reduce the frequency of communications with the spacecraft.

In designing and modifying a spacecraft, it is also possible to learn something more than tangible changes or hardward design. We learned about the reliability requirement and the very important need to check details carefully. It is a requirement that cannot be designed into a system on the drawing board. It actually consists in developing a conscientious contractor team that will take care to follow procedures and deliver a reliable product. Then it takes a careful recheck by the government team to insure that reliability has actually been built into the product. The smallest mistake in a man rated system can bring totally unexpected results. The unexpected is the rule in the unknown, and if man is going to live in the region beyond our atmosphere, he is going to live under rules or not at all. We have been aware of these new rules from the start of the satellite program, but they have not been brought to our attention so vividly as they have in the manned flight program.

If an unmanned satellite malfunctions we cannot get it back for examination. We can only speculate on the causes and try to redesign it to eliminate the source of the supposed trouble. It is necessarily a slow process of elimination. Here again, if a manned craft malfunctions, it can be returned to the ground by the proper action of the pilot. Then the why of the malfunction is revealed as well as the what. We knew what had failed in Gordon Cooper's flight, but we did not know why the system had failed until we got the spacecraft back for investigations and tests. Knowing why something occurred will give us the tools to improve spacecraft of the future.

AEROMEDICAL EXPERIMENTS

While we can redesign the equipment to accomplish the mission, we cannot redesign the man who must perform in space. Aeromedical experiments for new knowledge about space must simply answer one question. Can man adapt to an environment which violates most of the laws under which his body normally operates? The answer to the question at the end of the Mercury program seems to be an unqualified yes, at least for the period of one to two days.

The crushing acceleration of launch was the first concern. We knew he would be pressed into his couch by a force equal to many times the weight of his body. It was not definitely known whether he would be able to perform any piloting functions under these high "g" forces. The centrifuge program was started and the astronauts tested under this stress proved that man was not as fragile or helpless as we might have supposed. In addition to being able to withstand heavy acceleration, a method was developed of straining against the force and performing pilot control maneuvers.

Weightlessness was a real aeromedical unknown and it was something that the astronauts could not really encounter on the ground. The ability to eat and drink without gravity was one serious question we had to answer. In the weightless condition, once the food is placed in the mouth, normal digestive processes take over without being affected by the lack of gravity.

The next problem was the effect of weightlessness on the cardiovascular system, that is the heart and blood vessel system throughout the body. All types of reactions were possible in theory. In actual flight, a small and temporary amount of pooling of blood in the veins of the legs has occurred, but it is not serious nor does it appear to affect the performance of the pilot. For all pilots weightlessness has been a pleasant experience. All the senses such as sight and hearing perform normally during space flight. There has been no hallucination, no blackout or any other medical phenomena which might have an effect on man in space. We even experimented with drifting flight and whether the astronaut would become disoriented when he could not distinguish up from down or have the horizon of the earth for a reference. But each time the answer seemed to be that man could adapt as long as his basic needs for breathing oxygen and pressure were supplied.

Perhaps the greatest contributions to the program have come in the area of development of aeromedical equipment. Blood pressure measuring systems were developed that would automatically take readings and transmit them by telemetry to the ground. The biosensors were designed to pick up other information such as pulse rate and respiration rate. There were numerous small changes that were made to these systems to increase the accuracy of the data that we got back from the man in space. The in-flight studies of the pilot's reaction are probably the most complete medical records we have tried to keep on an individual. Their value has been to demonstrate that man functions normally in the space environment.

Related to the aeromedical studies in the environmental equipment that provides life support for the astronaut. We started with the basic Navy pressure suit for aircraft flying and modified it for performance in the spacecraft. We found it was desirable to eliminate as many pressure points as possible and have tailored the suits on an individual basis for each astronaut. There are two areas in life support which presented new problems to be overcome. First, there was the problem of circulation of air. In the absence of gravity, the normal rules of air circulation are cancelled, and the carbon dioxide breathed out by the astronaut would suffocate him. The air in the cabin would also have to be forced through the air conditioning system to keep the cabin area from overheating.

Secondly, there is the problem of the air supply itself and its possible effect on the spacecraft pilot. For conserving weight, a single gas system was desirable. But it was not known if breathing pure oxygen over long periods of time could have harmful effects. The Mercury flights and other research in a pure oxygen environment have proven that no injury to the body's system has been produced by using a one gas system.

SCIENTIFIC EXPERIMENTS

Man's role as a scientific observer and experimenter in space was another unknown in the program. Much of it was based on the ability of man to exist in space. It had to first be determined that he would be able to function normally and then the scientific benefits of the program could be explored. Man as an observer has proven his ability from the first orbital flight. The brightness, coloring, and height of the air glow layers was established. It was something a camera could not record nor would an unmanned satellite perform this mission. Man in space has the ability to observe the unknown and to try to define it by experiment. The particles discovered at sunrise by John Glenn were determined to be coming from the spacecraft by Scott Carpenter, and this analysis was confirmed by Schirra and Cooper.

We can send unmanned instrumented vehicles into space which can learn much about the space environment and the make up of the planets. However, the use of man to aid in making the scientific observations will be invaluable. The old problem of what and how to instrument for the unknown can benefit greatly from man's capability to pick and choose the time and types of experiments to be performed. We have learned much from the Mercury program through this quality of choice and we will continue to learn if man continues to be an important part of the system.

If we have learned more about space itself, we have also learned about man's capabilities in space. Many experiments have been conducted which have yielded valuable information for future programs.

Aside from the aeromedical experiments, man has been able to distinguish color in space, to spot objects at varying distances from the spacecraft, to observe high intensity lights on the ground, and to track objects near him. These observations provide valuable information in determining the feasibility of the rendezvous and navigation in Gemini and Apollo.

Pictures taken with infrared filters have aided the Weather Bureau in determining the type of cameras to use in their weather satellites. Special pictures have also been taken for scientific studies such as geological formations, zodiacal light, and refraction of light through the atmosphere.

CONCLUSION

The manned space flight program has changed quite a few concepts about space, added greatly to our knowledge of the universe around us, and demonstrated that man has a proper role in exploring it. There are many unknowns that lie ahead, but we are reassured because we are confident in overcoming them by using man's capabilities to the fullest.

When we started the manned space program five years ago, there was a great deal of doubt about man's usefulness in space. We have now come to a point which is exactly one hundred eighty degrees around the circle from that opinion.

We now depend on man in the loop to back up the automatic systems rather than using automatic systems alone to insure that the mission is accomplished.

We do not want to ignore the automatic aspects of space flight altogether. There must be a careful blending of man and machine in future spacecraft which provides the formula for further success. By experience, we have arrived at what we think is a proper mixture of that formula. Man is the deciding element, but we cannot ignore the usefulness of the automatic systems. As long as man is able to alter the decision of the machine, we will have a spacecraft that can perform under any known condition, and that can probe into the unknown for new knowledge.

THE MANNED ORBITAL LABORATORY

BY

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THE MANNED ORBITAL LABORATORY

by

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ABSTRACT

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The uses and the various possible design concepts of a Manned Orbital Laboratory (MOL) are discussed. The primary use of a MOL is the investigation of man's behavior and capabilities during prolonged space flight, leading to the decision whether artificial gravity is necessary in future advanced manned space vehicles. Secondary uses include development testing of numerous subsystems as well as conducting a number of scientific experiments. The design concepts reviewed range from the minimum MOL, which is a modification of the Apollo spacecraft to accommodate two men for periods of 100 days, through the small MOL, which is a Saturn I or IB launched laboratory subsequently supplied with a 4- to 6-man crew, by means of a ferry vehicle, to the large MOL, which is an advanced type Saturn V launched laboratory, operating with a 12- to 24-man crew. In conjunction with the laboratory concepts the logistics systems, like modifications of Gemini, Apollo or advanced new ballistic and lifting body re-entry systems are reviewed as well.

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I. INTRODUCTION

With the completion of the Mercury program and the strong efforts on Gemini and Apollo this nation is well on its way toward the development of an established manned space flight capability. It is difficult to imagine future technical growth without an ever-increasing use of space by man, extending to man's exploration of the planets. In order to achieve this expanded manned space flight capability many of the building blocks that make it up have to be developed to a high degree of perfection and tested under exact environmental conditions. One of those building blocks in need of testing is, of course, man himself. Therefore, it is reasonable to assume that for the purpose of laying a broad foundation for advanced manned space flight a manned space laboratory may be necessary.

The Manned Orbital Laboratory (MOL) may be, for many years to come, a basic research tool in space. It would be utilized at first to answer the basic question of whether man can live and operate successfully in space for long periods of time. While this biomedical experiment would be going on, other engineering and scientific research tasks which require the true space environment and/or the attention of a human operator might be carried out on board the station. Eventually, the MOL may develop into an operational space station functioning, for instance, as an orbital launch facility, a meteorological observatory or a space maintenance and rescue center.

II. APPLICATIONS

In order to determine the immediate requirements for an early laboratory, the various potential experimental uses must be evaluated. This evaluation will provide a basis for establishment of the configuration of a MOL. Is a minimal Apollo-type

MOL sufficient for the performance of a significant biomedical experiment? Or perhaps, the benefits of a truly multi-purpose MOL are so overwhelming in the long run that one should not expend unnecessary time and effort in going through the intermediate steps of building small space stations but, rather, proceed immediately with the development of a large laboratory in space.

Various government agencies and many industrial contractors have studied the potential uses of space stations for a number of years. These applications have been collected, analyzed and rated and are being continually reevaluated in terms of technical feasibility and ultimate value for the overall national space flight program. Only the more important categories are discussed here.

A. BIOMEDICAL APPLICATIONS

The most pressing mission requirement, and therefore the predominant purpose of the early MOL, will be the study of man's physiological and psychological response to the space environment and the determination of a man capability for performing useful missions in space over extended periods of time. Of ultimate interest are manned planetary missions which typically require one-year flight times. The validation of man s active role in space cannot be accomplished by simulation on earth because of one particular factor peculiar to space. This factor is "weightlessness." In order to fully understand this phenomenon and to make a valid decision as to how best to counteract the long-term effects of the space environment on man, all effects on man, during and after a prolonged stay-time in a weightless environment followed by a high deceleration re-entry, have to be closely evaluated and compared with earth-based simulation studies.

The final evaluation of all biomedical parameters will lead to one of the key decisions in the future manned space flight program. It will answer the question whether or not an artificial gravity field is required in man's life support environment or, in more operational terms, whether future manned space stations and spacecraft for extended missions (such as Mars and Venus exploration) must be rotated.

The biomedical studies will be especially concerned with the following areas:

1. Cardiovascular System

The maintenance of an adequate cardiac output, with properly oxygenated blood to supply all areas of the body, is vitally important since this is the mechanical transport system for the cellular nutritional needs and waste product removal. The existing knowledge of the role of the gravitational force field, or its absence, on circulatory dynamics is limited. What is known, however, points to the fact that cardiovascular dynamics will be altered significantly to the extent of causing symptoms which will interfere with adequate locomotive functions, with possible unconsciousness, upon return to a force field after a prolonged period of weightlessness.

2. Nutritional Functions

The role of a gravity field in the dynamics of food absorption, transport and utilization over prolonged periods of time is unknown at the present time.

3. Musculo-Skeletal System

The musculo-sketetal system has been subject to speculation as to the role of gravity in maintaining muscle mass (protein metabolic balance), muscle function and strength, and calcification of bones (mineral mobilization, deposition and balance). It is presently unknown whether these functions are gravity-dependent or primarily dependent upon maintenance of muscular contractions.

4. Pulmonary Functions

An area of vital importance is the long-term effects of partial pressures of oxygen in excess of sea level partial pressures. What kind of changes, if any, are initiated by an atmospheric composition dissimilar to earth's? How do these possible changes affect such pulmonary functions as ventilation, the mechanics of breathing and, more importantly, pulmonary ventilation-perfusion ratios during weightlessness? The definition and estimation of the significance of these questions are yet to be determined. Some of these could be duplicated here on earth, but interaction of all multiple factors cannot be predicted.

5. Biochemical System

Any endeavor which produces stress in excess of measured experience may cause havoc to the endocrine organs. Release of excessive amounts of hormones and enzymes, even to depletion, has been known to occur on earth. Much needs to be accomplished in understanding the significance of these fluctuations as they relate to the long-term functional usefulness of the individual and his well-being after return from the mission.

6. Psychiatric and Psychological Functions

Little is known in the area of psychiatric and psychological variations induced by small closed societies, isolation and artificial environments, and what is known cannot yet be adequately correlated. Much work must be done so that some adequate measure of assurance can be had that long-term space missions will not pose undue problems in this area.

7. Vestibular System

This area is related uniquely to artificial gravity produced by rotation and is concerned with the study of the effects of Coriolis and angular acceleration gradients on vestibular functions. Questions which must be answered relate to the degree of interference with function, habituation and effects of changing magnitude of Coriolis and angular velocity as a function of space station configurations

A biomedical facility in space will require flexibility so that any eventuality can be adequately measured and evaluated. This calls for a high degree of biomedical sophistication. This sophistication recommends serious consideration of the use of properly trained medical personnel for flight missions.

There are three successive objectives in the biomedical experiments:

1. Determine whether man can operate successfully under weightlessness for long periods of time (of the order of one year) and subsequently survive in good condition the environment of re-entry and normal gravity conditions thereafter.
2. If there are indications of difficulty in the weightless state, determine whether onboard reconditioning measures, like a double-ended trampoline, a low acceleration centrifuge or the use of pressure cuffs or drugs, will make the subject fit for operating successfully under prolonged weightlessness, followed by re-entry.
3. If there are conclusive indications that reconditioning measures are insufficient, determine the best means of providing artificial gravity and develop techniques for crew operations in the simulated gravity field.

Two approaches are possible for achieving the first biomedical study objective. One is to expose subjects to ever-increasing periods of weightlessness followed by re-entry to earth. This approach may be costly in terms of the number of required flights. The second approach is to simulate re-entry conditions by means of an onboard high speed centrifuge; however, more centrifuge research is still required to determine whether this type of simulation is sufficient and without disturbing secondary effects.

The Manned Orbital Laboratory must be designed in such a way that, if the results of the first biomedical study objective are negative, the second and third objectives can be carried out without major modifications of the program.

B. ENGINEERING RESEARCH AND DEVELOPMENT

While the first manned orbital laboratories should be considered a stepping stone toward extended earth orbit operations within the frame of the overall National Space Flight Program in determining man's capability to work and live in space, the ultimate goal of a MOL may be to provide a logical foundation to manned interplanetary space flight. The complex space vehicles employed in planetary missions may be assembled, serviced, checked out and launched through the active participation of an orbital launch crew working from or near an orbital launch facility. A manned space station serving as an orbital launch facility may increase the overall probability of success for such missions. Orbital launching, on the other hand, requires the solution of a variety of complex engineering development tasks such as assembly in space, check-out, launch procedures, fuel transfer, maintenance, repair, general operations and logistics, etc., and only after these problems have been studied in detail will one be able to assess the usefulness of an orbital launch facility.

Manned orbital laboratories, flying during earlier time periods, have the potential of providing useful facilities for developing and qualifying the various systems, structures, materails and operational techniques that will be required both for an orbital launch facility and for other future manned and unmanned space missions. Future systems and materials under development will require long-duration exposure to the space environment. Many parameters of this environment may be simulated in earth-based facilities; however, in many cases large volume and hard vacuum requirements favor space station testing. Furthermore, ground-based tests obviously cannot provide the conditions of weightlessness or partial gravity for extended periods of time. One should bear in mind, however, that only tests which cannot be effectively carried out on the ground should be assigned to the MOL.

Man's presence is helpful in the testing and qualification of systems in the space environment. The instrumentation required to monitor all the functions in a system to identify the cause and result of the many possible experimental responses and modes of failure would be highly complex and massive. Man could help for the following reasons:

1. He can calibrate and align equipment required for an experiment.
2. He can monitor experiments.
3. He can use his judgment to alter an experiment in progress to meet new objectives.
4. He can repair equipment whose failure could result in the premature termination of an experiment or at least seriously affect the validity of the results.

In the following discussion some of the more significant potential experimental groups for manned orbital laboratories will be identified to show the level of necessary effort in the area of engineering research and development.

1. Crew Systems

The performance and reliability aspects of advanced environmental control systems to provide cooling, heating, pressurization, etc., for future spacecraft configurations could be evaluated. Particular tests would yield data on the effectiveness of leakage detection systems to pinpoint micrometeoroid penetration and failure in hermetic seals. This, in turn, would lead to an assessment of sealing techniques to correct these penetrations and failures. The study of advanced life support systems and crew equipment under space conditions would yield valuable information to support man on long-term space missions. Emphasis should be directed to such areas as:

a. Closed-loop algae systems
b. Magnetic radiation shielding

c. Regenerative water supply systems.

d. Waste disposal.

e. Food storage and preparation.

f. Personnel restraining equipment.

2. Electrical and Electronic Systems

The performance and/or endurance capability of various solar and chemical power generation systems operating in space environment could be evaluated. Systems under test may also provide useful power for bonus experiments and serve as backup power systems. Various items of communication equipment, such as very high frequency devices, may be tested to develop improved space communications in terms of advanced components, optimum frequencies, bandwidths, transmission power, receiver sensitivity, reliability, etc. The performance characteristics of long lifetime advanced navigation and control systems may be studied and new guidance techniques evaluated.

3. Propulsion Systems

The effects of the space environment, especially weightlessness and long-time space exposure on ignition devices, restart capability, fuel sloshing, vortexing and expulsion could be determined. Various types of propellant actuation devices could be exposed to the space environment for extended periods of time and then actuated and analyzed. Tests could be conducted on various fuels and oxidizers in different propellant tank configurations and with various insulation techniques and materials. Electric propulsion systems could be proof tested under true space conditions, and the behavior of rocket exhaust plumes could be studied.

4. Structures and Materials

Many simultaneous effects of the space environment such as meteoroids, vacuum, radiation and temperature cycling on various characteristics of materials and structures are difficult to be meaningfully reproduced in ground tests. This lack of information introduces uncertainties in spacecraft design that may be serious enough to impair future space missions or require over-designed systems with unnecessary weight penalties. For instance, ablative materials could be exposed to space vacuum and temperatures extremes for long periods of time to evaluate their integrity. An effective meteoroid protection research program could be undertaken with the aid of MOL experimenters who could help deploy large meteoroid bumper areas, examine penetrations and alter the materials to devise optimum protection schemes. There is some recent evidence that a deep vacuum forms in the "wake" of a low altitude satellite. This would make the MOL suitable for deep-vacuum experimentation on various materials and mechanical systems.

5. Extravehicular Operations

For extended extravehicular operations man must be well versed in the capabilities and limitations of individual propulsion units, extravehicular suits and portable life support systems. The MOL would provide a test bed to train personnel for future lunar and planetary missions.

6. Developmental Flight Testing

Also of importance is flight testing of large unmanned satellites and space probes or qualification testing of advanced manned satellites. Present satellite programs require a costly and timeconsuming development flight test program necessary to obtain reliable flight hardware. This is mainly due to the fact that we have not yet learned to build adequate ground simulators, and, thus, testing of final satellite configurations on the ground does not allow an isolation of all design deficiencies. No effort should be spared to improve ground testing, but if that proves still inadequate, then one could use the MOL as a development flight test facility. By orbiting the test article as a "tag-along" near the MOL, thus allowing visual observation and a short command and telemetry link, diagnosis and repair of satellite malfunctions would be possible through extravehicular operations of the MOL crew.

C. SCIENTIFIC RESEARCH

While the Manned Orbital Laboratory performs the biomedical experiments and the engineering research and development tasks, some of its facilities may be allocated to perform scientific research. It should be pointed out that some scientific experiments, given high priority today, may be relegated to a lesser rating or even disregarded by the time the space station becomes operational. This will be the case when unmanned satellites and space probes have gathered enough significant information in a particular problem area during the intervening time between experiment conception and experiment initiation on the space station.

1. Astronomy

An orbiting space station could provide an astronomical observatory that would greatly increase the angular resolution and extend the wave length range that is possible in earth-based observatories. However, some experiments on an orbiting observatory might require pointing accuracies as stringent as 0.1 second of arc with photographic exposures for as long as one hour or more. Such stability may be difficult to achieve, particularly because of man's disturbing presence.

A possible solution might be an unmanned astronomical platform in close proximity to the space station with a radio command and an optical data link between the platform and the MOL

There exists a large range of astronomical observations that may be made from an orbiting observatory. The more significant of these may be classified under the following headings:

a. Ultraviolet, visible and infrared studies of the planets, the solar disk, the solar corona, galaxies, nebulosities and interstellar gases.

b. Ultraviolet, visible and infrared studies at very high resolution of stellar systems and a search for planets of nearby stars.

c. Gamma and X-ray telescopy.

d. Radio telescopy.

Only a few basic instruments would be required to do all the studies listed above if man were present to make changes in systems and programs, change attachments to the basic instruments, align and calibrate.

2. Biology

A Manned Orbital Laboratory could contribute to the search for extraterrestrial life in a number of ways. It could serve to collect and to analyze the upper terrestrial atmosphere for microorganisms, including such organisms possible in micrometeoroids. In addition, a space station could provide a biological laboratory for the preliminary analysis of extraterrestrial samples to determine if they display a contaminating danger before they are sent to earth for a complete analysis. And finally, a MOL provides an opportunity for utilizing the unique aspects of the space environment to analyze the general relationship that exists between an organism and its environment. Studies would be concerned with environmental effects on photosynthesis, biological rhythms, metabolism, and growth and development of organisms as follows:

a. Study of various physiological systems in high animals.

b. Study of embryology.

c. Growth of organisms.

d. Plant physiology.

Most of the required equipment to perform the above studies would be common to that required for biomedical applications, and sharing of equipment would stamp most of these studies as bonus experiments.

3. Physics and Chemistry

Very few experiments suggested for Manned Orbital Laboratories in the area of physics and chemistry are actually basic in their nature. The majority of experiments of concern to the chemist and physicist are also of major concern to the space station designer. Possible exceptions are basic studies like chemical reaction kinetics, surface tension effects, heat transfer phenomena, liquid-gas separation studies under zero gravity and partial gravity conditions.

4. Space Environment

It is anticipated that unmanned satellites and space probes will have contributed significantly to the investigation of many present problems in the space environment area by the time space stations become operational. Many investigations, however, may require the presence of man before the problems can be completely resolved. Also, it is possible that a number of experiments that could be individually conducted on advanced unmanned satellites would be collectively justified for a manned space station. Experiments in this category include studies of magnetic fields, radiation, meteoroids and wave propagation phenomena.

III. MANNED ORBITAL LABORATORY DESIGN CONSTRAINTS

A. ARTIFICIAL GRAVITY

The Manned Orbital Laboratory, like any other space vehicle, must be designed within a large number of design constraints, and the design must be optimized for its purpose. Particularly since the MOL is intended to be a space laboratory in the full sense of the word the designer has to consider first the adaptability of any concept to the requirements posed by the experimental applications.

Several surveys of the potential engineering and scientific uses of an orbiting laboratory show that about half of all experiments require zero gravity, while almost all the rest are independent o the gravity field. Relatively few applications call for artificial gravity. That requirement may arise primarily from man himself. For man, the lack of gravity forces may cause physiological problems and varying degrees of physical inconvenience. If earlier programs like Gemini or Apollo do not already indicate a clear need for artificial gravity, it will be desirable to provide the MOL design with sufficient flexibility such that it will be applicable for future operational use, regardless of the outcome of the "zero gravity decision." This, then, calls for a "zero gravity" MOL which can be later converted to a rotating station if necessary.

Artificial gravity overcomes the disadvantages of weightlessness and brings the astronaut and all equipment closer to an earth environment, but the rotation necessary to produce artificial gravity, unfortunately, introduces certain operational and physiological problems with respect to the crew and the systems installed in such a station. Also, in the area of the on-board installed systems, rotational factors influence the design of such components as antennas, docking devices, crew and cargo transfer, guidance systems, and viewing the earth or certain designated portions of the sky. These rotational considerations are not overriding liabilities but rather must be treated with consideration and ingenuity in the conception and design of systems and their installations.

The rotation of the station introduces various forces; the primary one, which is the Coriolis effect on individuals, presents an additional factor to the environment to which man is not ordinarily exposed. This requires that man either adapt to this additional factor or that certain types of provisions be made to facilitate his activities in the space station. Man has a rather narrow tolerance zone in terms of rotational parameters such as radius and rate of rotation. The interrelations between the rotational parameters are illustrated in Figure 1, which shows the present human factor design envelope for man. The tolerance limits which define this envelope have been established by many specialists on human factors, but are based only on a bare minimum of experimental evidence conducted under a different environment from that which exists in a rotating space vehicle. The limits that encompass this envelope are the upper limit on the gravity level, the upper limit on angular velocity and a lower limit on rim speed. The upper limit for gravity level was selected as 1 g; the upper limit on angular velocity was set at 4 rpm, above this, based on centrifuge experience, vestibular disturbances may appear when the head is turned rapidly about an axis perpendicular to the axis of rotation of the station; the lower limit on rim speed was chosen at 20 ft/sec below which a 50 percent change in apparent gravity occurs when a crew man walks at a nominal rate (4 ft/sec) in a tangential direction rather than standing still -- psychologically a rather disturbing situation (Reference 1). Another limit, although not defining this envelope, is the minimum radius where the gravity gradient from head to foot is not great enough to disturb the crew. That gradient should not exceed 15 percent, which indicates a minimum radius of 40 ft.

All these artificial gravity considerations indicate that it is necessary to consider fairly large radii of rotation, say in the vicinity of 75 ft. This in turn challenges the designers' ingenuity in packaging the station within the bounds of launch vehicle payload envelopes.

B. DYNAMICS AND STABILITY

The additional benefits of station rotation for the purpose of creating artificial gravity are that, if the axis of rotation is the principal axis of maximum moment of inertia, the station will tend to be spin stabilized. To provide mass distribution such that the stability requirement is satisfied the configurations tend toward those of spinning discs, flywheels or long cylindrical sections (Figure 2).

In spite of inherent stability, however, there are problems associated with the dynamics of spinning bodies. These originate from the "wobbling" motions and elastic oscillations produced by imposed disturbances such as mass shifts created by crew motions and cargo shifts and external torques resulting from docking impacts. Undamped wobbling motions produced by such disturbances would subject the crew to oscillatory motions which, coupled with station rotation, could cause nausea and disorientation. For instance, an instantaneous motion of a man in a direction parallel to the station's spin axis will make the axis move between two limiting curves defined by the station inertia and angular velocities (Figure 3). The resulting wobble will appear to the crew like the rolling of a ship. In addition, the elastic response can further complicate this problem by producing excessive cyclic loadings and by interfering with the station control. Therefore, the smaller the amplitude of this motion the more inherent stability a configuration possesses.

The maximum wobble angle created by an instantaneous mass shift is calculated from the relationship (Reference 2).

$$\alpha = \tan^{-1} \frac{2\, I_{xz}}{I_z - I_x}$$

where α is equal to twice the principal axis shift measured from the original position. I_{xz} is the product of inertia created by a mass shift in the xz plane ($I_{xz} = 0$ for no wobble), and I_x and I_z are the moments of inertia of the station about their respective axes. For instance, in an undamped system a typical 30-foot station would have a 13-degree maximum wobble angle and an apparent rolling of from 0 to 5 degrees for an instantaneous motion of a crew man in a transverse direction ($I_{xz} \approx 4000$ slug ft^2). In the case of a 150-foot station the situation is considerably improved, where the corresponding maximum wobble angle is 1 degree.

Considerable amount of work has been done on the development of efficient stabilization and attitude control systems for space stations. For instance, one can consider a combination of a wobble damper and a pulse-jet damping and orientation system (Reference 2). They complement each other in eliminating wobbling motions and aligning the station's spin axis in the desired direction. Such a wobble damper may consist of a spinning flywheel which can be precessed to provide reaction moments that oppose the disturbance torques.

The level of stability to be provided is a subject of optimization. Relative comparisons and trade-offs associated with the stability levels are to be made, considering, for instance, the amount of propulsion which meets these stability levels, system complexity, reliability associated with the stability level, and experimental and crew tolerance requirements. For example, it appears to be more more plausible to install astronomical equipment either in the immediate adjacent vicinity of the space station or on an internal independent stabilized platform because of the precise stability tolerance levels required.

About 25 percent of the proposed experiments require pointing accuracies to less than 1 degree, while about 40 percent require pointing to an accuracy of between 1 to 10 degrees. Thus one can assume that a suitable station would have a control system capable of maintaining the attitude below 10 degrees, while the precise requirements of less than 1 degree would be provided by separately stabilized platforms.

A mass control system might also be integrated into the overall stability system of a rotating space station. As a logistic spacecraft docks with the space station and proceeds to transfer crew and cargo to the space station, large amounts of mass are moved into the various areas of the space station, thus upsetting the stability of the station. It may be necessary to install a mass control system that would transfer liquids (water, urine, waste products or fuels) to various locations in the station to overcome these disturbing mass transitions. This would assist in minimizing the penalties associated with basic stability and control systems.

C. SUBSYSTEM CONSIDERATIONS

The space station has a number of types of systems installed onboard to meet the various requirements for overall space station operations and activities. These include the environmental control and life support system, power generation and energy storage system, communications system, onboard instrumentation system, and various types of mechanical systems. The technology to achieve the concept, development and installation of these types of systems is currently available and in its application appears to be, in general, less demanding and stringent than that currently being applied to the Apollo lunar-landing program. Nevertheless, in the design of such systems, ingenuity is required to achieve the optimization and efficienty necessary for onboard service, maintenance, overhaul and various other types of support activities to maintain a long operational lifetime. Current spacecraft systems such as those of Mercury, Gemini and Apollo are, with minor exceptions, not designed for onboard maintenance and service. On the space station, if in-flight service and maintenance are to be achieved, systems must be designed from their preliminary inception with this capability as a major design objective.

With respect to particular systems, certain considerations must be given proper attention. In the case of the environmental control system, most of the components are now available. What is required is the optimization of these building blocks within e station in terms of the oxygen supplies, fan motive power to circulate environment atmosphere, heat exchange methods to provide the heating and cooling as required, CO_2 absorption and regeneration devices, water separation techniques, water storage and waste management.

One area which requires development and implementation in the space station environmental control system is the ultization of the CO_2 absorbed from the respiratory processes of the crew which can be collected and broken down into either water or oxygen for further use. This is a partial closing of the loop which is a step toward the ultimate environmental control system of a completely closed ecological cycle. Such types of systems would be essentially inorganically closed to start with, i.e., they would not attempt to process all the waste products of man and regenerate these products in terms of food.

The second, and more advanced approach, is the completely closed ecological system where all the waste products of the crew are collected and regenerated for use in providing oxygen, water and food for extended missions. This type of closed ecological system, although not essential in the MOL, could be evolved and utilized as time proceeds. Such a system could show definite advantages and savings in the overall supply and expendables requirements for long-term missions such as the planetary mission or a long-time lunar base.

In the case of power generation and energy storage, the space station requires a large power source as the basic energy supply for the various kinds of activities that take place onboard the station. It is generally estimated that about 1 kw per man is required. Various types of energy systems are available, and the current problem is to select the optimum system for the time period and activity that takes place in the station. Currently, various types of static and dynamic solar power systems, nuclear power systems of the reactor and isotope type, fuel cells and dynamic engine types are being evaluated. Each type of system has advantages in its own area, time period and operational duration. The problem at the moment is to establish the most optimum system for a particular set of criteria based on the launch date, the operational duration and the power levels necessary to be supplied.

The static solar power system technology is available at the present time. The dynamic solar power system requires intensive development and implementation if it is to be useful in the time period that has been suggested for the space station. All solar power systems face orientation difficulties in rotating space stations. Similarly, nuclear and isotope power systems must be implemented with additional development funding and activity if they are to be available in the late 1960 period for space station utilization. Other power systems, such as fuel cells, are currently being developed for the Gemini and Apollo programs and could possibly be used for short durations, at least in the initial portion of the space station program if optimization criteria show that this would be desirable.

One of the main problems associated with the solar power supply is that of energy storage. Inasmuch as the space station would rotate about the earth approximately once every 90 minutes and pass through the shadow of the earth where the energy generated by a solar power system would not be available, the space station must rely on its energy storage system. This means that over a period of time a great number of power cycles are imposed upon the power system in terms of power drain and power input. At the present time there are no batteries capable of withstanding such a large number of cycles for periods of time of up to 5 years, the ultimate requirement for some of the larger stations. Other methods have been suggested for energy storage, including the rotating flywheel, which also might be used as a part of the stabilization control system.

Another area which requires ingenuity and intelligent design is that of the various kinds of mechanical systems. These include the physical docking facilities where the actual mating of ferry and logistics spacecraft takes place after station rendezvous. It is necessary to develop the best possible docking system to permit routine and automatic conduct of this kind of operation as early as possible to achieve adequate, reliable operational support. Much consideration is currently being given to the matter of airlocks and seals at various openings and joints. Sealing and leakage is one of the most important problems currently associated with the space station design. Leaks cause the loss of expendables which are expensively transported from earth by the logistics spacecraft. Mechanical and rotating seals and materials associated with these devices are among the potential leakage areas. These devices must be operational and reliable for long periods of time in the space environment; the designer must be very selective in his choice of materials, processes, and finishes if the long-term utilization and reliability necessary in the space station are to be accomplished.

In the area of the data handling and communication systems, essentially all the building blocks of the system are available now. The main problem confronting the system designer is to optimize the systems in such a manner as to meet the rather high demands of bandwidth, data storage and processing.

D. ENVIRONMENTAL PROTECTION

The space station structure has to be designed to provide for efficient environmental protection against radiation and meteoroids besides satisfying the usual structural demands. The meteoroid protection problem is of great importance. Since large surface areas and long exposure times are involved, penetrations may have to be expected, and in that case internal equipment has to be arranged in such a way as to allow access to the walls for repair. On the other hand, equipment judiciously arranged adjacent to the walls can provide for additional radiation protection.

Radiation shielding requirements presently represent the greatest area of uncertainty in MOL weight estimates because of uncertainty in crew tolerance and insufficient understanding of the radiation environment. Shielding requirements in the MOL are much more stringent than those of Mercury, Gemini and Apollo, not only because of the much greater exposure times but also because the accumulated dose should be kept low enough to avoid masking measured physiological responses to weightlessness.

The radiation sources that are important to the design of radiation protection are:

1. The naturally occuring Van Allen belts containing primarily electrons and protons.
2. Artificially created electron belts caused by high altitude nuclear tests.
3. Solar flares.
4. High energy galactic radiation.

For low altitude orbits that lie below a geomagnetic latitude of about 40 degrees, solar flares present no problem because of the shielding effect on the earth's magnetic field. For latitudes greater than 40 degrees, they are statistically a problem for long stays and can require substantial shielding. The largest recorded solar event, in terms of dose (July 14, 1959), resulted in a considerable particle flux at latitudes even as low as 30 degrees but essentially no flux at lower latitudes. A spacecraft with 1 g/cm^2 of aluminum shielding would have received a negligible dose from this event at inclinations below 30 degrees, whereas the dose would have been about 200 rad at inclinations a few degrees higher at a 200 nautical mile altitude (Reference 3). The maximum permissible emergency dose for Apollo astronauts is presently set at 54 rad/year to the blood-forming organs and 233 rad/year to the skin.

The galactic radiation creates a free space dose of less than 10 rad/year behind a reasonably thin shield of medium atomic weight material. For orbits below 40 degrees latitude this is reduced to less than 1 rad/year.

Because of such considerations as booster payload capabilities, launch sites and tracking station locations, the early manned satellites will operate considerably below an altitude of 1,000 miles and will probably have an inclination of between 28 and 30 degrees geographic latitude. For these conditions the only significant source of radiation hazard are the protons of the inner Van Allen belt and the artificially produced electrons from nuclear tests. The Van Allen belt proton radiation is fairly well known, but for future launch times there is the unresolved question of how fast the artificially produced electron flux will decay and hence how great a hazard it will be. Assuming a simple exponential decay one could predict that there would be almost no artificial electron flux by 1967, but satellite data show a definite tendency for the decay to be more complex, and that the flux around 1967 may not be very much less than it is in 1963 inside the magnetic anomaly which is located above the South Atlantic off South America and which contributes most of the integrated flux encountered by a low altitude satellite (Reference 4).

From the standpoint of reducing the radiation hazard it is desirable to place manned satellites in orbits which are at an altitude as low as possible consistent with the satellite decay period or orbit-keeping requirements, since the radiation fluxes decrease with decreasing altitude below the inner Van Allen belt. Because of desired life times from 1 to 5 years and space station size the air drag effects become appreciable. As an example, consider a MOL having a total weight of 50,000 lb and a W/C_DA of 15 lb/ft^2. Figure 4 shows the increase in propellant requirement for orbit keeping as the maximum altitude decreases, as well as the significant savings in total fuel requirements as the frequency of reboosts is increased. The necessary propellant will probably have to be delivered to the MOL periodically by means of a logistics or resupply spacecraft. Thus the maximum orbital altitude is not only governed by the radiation shielding requirements but also by resupply vehicle performance.

IV. MANNED ORBITAL LABORATORY DESIGN CONCEPTS

A. GENERAL CONSIDERATIONS

As previously noted the Manned Orbital Laboratory is a space flight system designed to extend man's capability to live and work in the space environment for periods of a month to a year or more. There are three classes of experiments which the MOL is to accommodate: Biomedical research, engineering research and development and space science research.

The first class requires that the MOL be able to carry sufficient medical equipment to determine and develop the techniques required to sustain man in the space environment for long periods without degradation of health or performance.

The second and third classes require that the MOL be large and flexible enough to be compatible with a wide variety of engineering and scientific research tasks which can profit from man's presence as an experimenter. This may also include the requirement for extravehicular operations, rendezvous, docking, fuel and material transfer, as well as space construction, repair and maintenance.

A survey of the requirements listed by various biomedical groups shows that the weights estimated for the biomedical instrumentation are under 250 lb, that in all cases the total amount of power required is less than 100 watts and that the volume of the instrumentation required is somewhat less than 10 ft^3. This does not include onboard centrifuges or elaborate psycho-motor testing equipment. From these numbers one can conclude that the biomedical instrumentation required, with the possible exception of a high speed human centrifuge, does not provide a significant constraint on the MOL configuration. It must be stated, however, that a shirt sleeve environment will be necessary, as well as sufficient room to perform the exercises needed for continued health.

A survey of the engineering and scientific experimental requirements shows that the average power need for each test is less than 200 watts, the average volume for the equipment less than 6 cubic feet per test, while the average equipment weight per test is less than 160 pounds. These figures essentially show that early payloads will be small and thus the size of a MOL depends more on the launch vehicle size, the schedule required to complete a given number of tests and the resupply mode used than on configurational restraints imposed by individual experiments.

For several years the major aerospace companies, NASA Centers and the Air Force have been studying the feasibility of a wide range of space station concepts. Although there are many small differences in the proposed concepts a broad breakdown into three basic categories is possible. These categories are the minimum, small laboratory and large laboratory concepts.

The minimum concepts, in general, make maximum use of available hardware and are considered because they require the shortest development lead times and minimum resources. One successful launch would provide an immediate capability for two men to spend on the order of 100 days in a zero gravity environment. Extensions in stay time and alteration of the concepts to provide simulated gravity can be incorporated in a minimum concept plan.

The small laboratory concepts require development of a separate module having life support provision and room for appreciable experimentation. This module is considered a relatively simple development because, unlike the Mercury, Gemini or Apollo spacecraft, it does not require a capability for rendezvous or docking propulsion, de-orbit retro thrust, re-entry, landing and recovery. The small laboratory, launched by a Saturn I, Saturn IB or Titan III booster provides living area for from 4 to 6 men and would be designed for at least a 1-year lifetime. Sufficient weight margin may be available for providing artificial gravity when needed. The small laboratory concepts are predicted on the use of separately launched crew ferry and resupply systems.

The large laboratory concepts generally require a booster of the Saturn V class and separately launched crew ferry and logistics systems. Such laboratories provide an extensive capability for performing a wide range of experimentation in space. These generally have a crew of from 12 to 24 men and, because of the major investment in equipment, probably would be designed for up to a 5-year lifetime. Although the large laboratory requires fairly sophisticated design procedures, it does have the feature of providing zero gravity and artificial gravity conditions simultaneously by means of a central non-rotating hub.

The following is a review of the various concepts, highlighting their advantages and disadvantages and including a discussion of operational and logistics requirements.

B. THE MINIMUM MOL

Of the several minimal concepts proposed the Extended Apollo is an example (Fig.5). The Extended Apollo consists of modified Command and Service Modules which would be launched by a Saturn IB. The Serivce Module would be rather extensively modified by off-loading propellants and providing additional life support stores and stabilization propellant for an extended stay-time capability. Although the Service Module engine is considerably larger than would be required to provide de-orbit retro thrust, it would be a proven and available engine and, therefore, would have a certain advantage over a newly developed retro package. This configuration can probably provide a 100-day capability for two men to live in the Command Module. By launching additional Apollos each 100 days and transferring the men, continuous stay capability can be achieved.

The Apollo Command Module is limited in that it provides only about 360 ft^3 of volume for its inhabitants. Various alternatives have been proposed to overcome this lack of volume, such as modifying the Service Module so that a portion could be inhabited or building an inhabitable module in the transition section between the S-IVB stage and the Service Module (Figure 5).

Proposals have been also advanced to leave the S-IVB stage attached, subsequently deploying it by means of telescoping tubes and/or cables, and thus provide a rotational capability for the creation of artificial gravity (Figure 6). This configuration not only places the crew close to the rotational comfort zone but also provides for good rotational stability with a wobble angle of less than 1 degree.

Of course, either of these latter alternatives would be such a major undertaking that this could no longer be considered a minimum concept solely designed for the "zero g decision." The basic advantage of the Extended Apollo minimal concept is its simplicity and relatively early availability, achieved at the expense of non-optimum design.

C. THE SMALL MOL

The small MOL is characterized by a 4- to 6-man crew capability. It has the attractive feature of consisting primarily of a simple inhabitable module which requires no assembly or deployment in orbit. In this concept the use of already developed hardware is emphasized with the exception of the laboratory module and possibly some internal subsystems.

Figure 7 shows a typical zero gravity MOL vehicle. It is a cylinder of approximately 2,000 to 4,000 cubic feet in volume and has a docking hub for attachment of manned ferries and resupply spacecraft. Most concepts show two compartments, one of which has especially heavy radiation shelter during periods of intensive radiation flux increases.

Like the minimal MOL, the small MOL is basically a zero gravity station, but most concepts are conceived in such a way that they can adapt to a negative outcome of the "zero g decision." In order to provide an artificial gravity field for the crew in the laboratory, the MOL and the expended upper stage of the launch vehicle are rotated about their common center utilizing a connecting system of cables or some form of rigidized structure. As part of the planned biomedical experimentation or as a crew reconditioning device, the use of an internal or external centrifuge is being considered in the design concepts.

Two launch vehicles classes are being considered for the small MOL systems. The first is the Saturn I-Titan III-Saturn IB class, wherein payloads could vary between 18,000 and 28,000 pounds. The second is the Atlas Agena-Titan II class, having payloads from approximately 5,000 to 7,000 pounds. The laboratory itself requires one of the large vehicles for its launch booster. The smaller vehicles may be needed for ferry and resupply operations.

The MOL and the last booster stage would be injected unmanned from Cape Canaveral into a 160- to 200-nautical mile circular earth orbit with an inclination of somewhat less than 30 degrees. Provisions would be contained for supporting the MOL and a two-man crew for about two weeks. Critical MOL systems, such as the life support and power systems, would be activated by ground command and monitored by telemetry for a sufficient time to determine proper operation prior to the initial manning operation.

Regardless of the method of MOL launch, ferry and resupply operations are required for any extended duration MOL mission. These operations are required to replace the crew, provide life support and stabilization expendables, replace experiments and provide fuel or possibly propulsion units for orbit keeping or changing.

Crew replacement could be accomplished by a ferry spacecraft using launch, rendezvous, re-entry, landing procedures, operations and landing sites currently planned and being developed for the Gemini program. The application of an Apollo-Saturn ferry vehicle is also being considered which has the additional capability of carrying supplies with the crew. The choice between Gemini and Apollo ferries and their respective boosters is presently unresolved and will depend on the operational requirements for crew replacement and resupply.

In the case of a Gemini-Titan II ferry concept, there is little payload margin for logistics cargo; the latter could be delivered by a separate resupply spacecraft of the Atlas-Agena D class. This logistics spacecraft would be equipped with control and propulsion systems for maneuvering and docking which are controlled remotely, probably by the MOL crew. The first resupply spacecraft would be launched any time within the first two weeks after the first two-man crew has boarded the MOL. It could carry about a 90-day supply cargo, thus necessitating a logistics launch every three months. To be fully effective, the craft with its launch vehicle must be capable of providing consumables to the MOL on a reliable schedule; in addition it must be able to accept some degree of emergency demand.

The requirements on the ferry vehicle are that it must have a round trip capability and always be ready at the MOL for emergency evacuation. The frequency of ferry flights is quite dependent on the station experimental requirements. As noted before, the problem of determining the effect of weightlessness on man's ability to withstand re-entry forces requires that the astronauts be exposed to re-entry decelerations after ever-increasing periods of weightlessness. In order to lay the ground work for future planetary flights, man's reaction up to a one-year exposure to weightlessness must be explored. This part of the biomedical experiment can be performed by means of a carefully planned crew rotation schedule, which may be the key feature in the ferry requirements.

For the purpose of illustration, Figure 8 presents a possible crew rotation schedule. The plan is based on a four-man station with a one-year mission duration and five crew transportation launchings. After the MOL has been placed in orbit and its components adequately checked out, the first ferry vehicle transports two men to the laboratory. Thirty days later the second ferry vehicle is brought up, and if all has proven well for the first two men the second will remain to complete the crew. Thirty days later, the third ferry vehicle with two astronauts would arrive and return carrying one of the first crew members who has been exposed to weightlessness for sixty days. One of the astronauts on the third vehicle would return with it as the pilot for safety since it is possible the first astronaut's exposure to weightlessness might have caused him to lose his ability to operate under high accelerations.

If the return trip and ground medical examination of the first astronaut have proven him to be in good condition the program continues as shown on the chart. During all of this one of the first astronauts has been kept in space the complete time, and he would provide the total 360-day experience. Note that in this scheme six other men would have been tested at times ranging from 60 to 300 days in orbit.

It should be pointed out, however, that although this crew rotation schedule permits the MOL with a one-year lifetime to gather a one year's accumulated weightlessness experience it is inherently risky. Suppose that the man returning on the fourth ferry who has been in space for 100 days experiences severe difficulties on reentry; then it is almost certain that the original subject intended for the one-year stay should be even in a worse condition, since at that time he would have accumulated 130 days in weightlessness. This dilemma can be avoided by a more conservative crew rotation schedule where the stay time data is built up on a progressive basis. This, of course, requires MOL lifetimes of the order of two years and a greater number of ferry launchings to eventually accomplish the one-year stay time experiment. This discussion points to the fact that a analysis of all operational implications and a thorough examination of the use of a centrifuge as an alternate method is necessary.

D. THE LARGE MOL

The large MOL is characterized by a crew ranging from 12 to 24 men and a requirement to be launched by a Saturn V booster. The size ranges from 150 to 200 feet in diameter, and internal volume is on the order of 50,000 ft^3. Some typical approaches which have been studied to date, although in no way all-inclusive, are shown in Figure 9. For comparison purposes a small MOL is also shown in this illustration. The large station studies have ranged from inflatable toroidal concepts to huge stations assembled in orbit. The hexagonal configuration shown is a station composed of rigid elements. It would be carried to orbit as a compact unit and deployed automatically.

The major feature of most large MOL concepts is that they provide for continuous rotation, thus creating an artificial gravity field. Non-rotating central hubs can be utilized as zero gravity laboratories. Radial spokes would be areas of varying gravity fields as one proceeds toward or away from the rim of the station.

The size of the station, the large crew and the varying gravity fields would allow the large MOL to function as a versatile space laboratory, and it could be adaptable to operational growth into an elaborate orbital launch facility. These features, of course, are acquired at greater expense in development costs and time and in operational costs.

One of the large rotating MOL configuration designs, which at the present time is being studied in greater detail, is the three-radial module type (Figure 10).

It is comprised of a hangar-type hub area and three radially-deployed modules. The diameter of this station would be approximately 150 ft, and it would rotate about its axis of symmetry at 3 to 4 rpm. The station would generally be oriented to point its axis of rotation in the direction of the sun so as to best utilize the solar-cell power plant deployed outboard of each radial module.

The hub of the station would contain an environmentally controlled area for service and checkout of logistics spacecraft, and a zero gravity laboratory would be located in a circular area below the hangar. The zero gravity laboratory would not be rotated but would be mounted on bearings to allow for the relative motion between it and the rest of the station (Figure 11).

During launch the radial modules would be folded down so that the axis of their cylindrical areas would be parallel to the axis of the hub. The sequence of launch operations is shown in Figure 12. The space vehicle is launched with the space station unmanned and with a crew of six in a modified Apollo logistics spacecraft atop the space station.

After injection into orbit, deployment of the radial modules is initiated. On completion of deployment, the ferry spacecraft is separated, performs a turn-around maneuver and docks with the station. The ferry is then towed into the hangar area, and the crew transfers into the space station to activate the onboard systems. In this concept no extravehicular operations are required. Once the systems are activated the station is then spun up to the required angular velocity.

In general the large MOL and small MOL requirements for ferry and resupply systems differ only quantitatively if crew replacement is not strictly dictated by the biomedical experiment. Certain aspects of the efficiency of usage of the payload capacity of large launch vehicles or tradeoffs between payload and rendezvous ability, when coupled with the associated reduction in launch cost per pound of payload, make a large ferry an attractive concept.

The development of a resupply vehicle or a combined resupply ferry using Saturn I launch capability will reduce the total number of launches necessary for large MOL support. A possible modification of the Apollo spacecraft to carry 4 to 6 men might appear as is shown in Figure 13. Effective support for differing MOL crew sizes and replacement schedule requirements can be satisfied by the availability of such a 6-man carrier. Full utilization and cost economies realizable with even larger launch vehicles (such as Saturn IB) can be expected to generate designs for even larger ferry vehicles such as a 12-man ballistic re-entry ferry logistics vehicle or a 12-man lifting body vehicle.

After sufficient knowledge of the requirements imposed by MOL design and operational characteristics is established, optimization of the design of both these large resupply ferry vehicles will take place. Eventually, with special attention paid to flexibility and reusability, a choice will be made identifying the particular configuration and size to best provide economic support for the large MOL.

V. CONCLUSION

It can be seen from the foregoing discussions that the Manned Orbital Laboratory could be the logical forerunner of many manned operational systems. Since it would be a very costly undertaking, one should drive toward consolidating the varied interests of the various federal agencies having a potential operational mission in space in planning for a single multi-purpose Manned Orbital Laboratory.

The NASA and the DOD are now conducting advanced exploratory studies of a MOL, both in-house and by contract with industry. As planning progresses each agency will appraise objectives, concepts, related programs, resources and future courses of action deemed desirable in the national interest. At the appropriate time, coordinated DOD-NASA recommendations concerning the implementation of the program will be submitted to the Administration for approval and decisions on the management approach.

The fundamental question which faces all at the present time is that of the purpose of a space station. Once a clear understanding of the purpose is reached and basic feasibility of the ideas established, a more thorough evaluation of the design concepts can be undertaken which would lead to a preliminary design and eventually program execution.

The NASA has a multi-facet study program under way to supply the information necessary to determine how beneficial a Manned Orbital Laboratory program is to this nation and to formulate a proper technical approach once such a program appears desirable. The NASA has studies under way in three major areas:

A. Mission Definition.

B. MOL Configurations.

C. Logistics and Operations.

The mission definition studies are being carried out to establish the experiments to be performed onboard MOL. To that end NASA had solicited recommendations for applications from numerous scientific engineering and military sources and is presently evaluating those suggested uses through various panels of experts. Since it appears that the biomedical experiments leading toward the "zero g decision" will comprise the primary use of an early MOL, particular attention is being devoted to this area of studies. These studies as well as those in the engineering and scientific fields are to lead to a definition of the experimental requirements in terms of equipment, operations, crew capabilities, logistics and laboratory size measured against relative returns. With an eye to the future, studies of orbital launch operations are also being undertaken.

Following in close coordination with the mission definition activities are studies of various MOL configuration concepts. Under investigation are minimum, small and large MOL concepts. Various concepts are being compared for their effectiveness to cope with the demands posed by the applications, design constraints, costs and schedules. From the great multitude of possible configuration concepts a smaller number will be selected, and eventually one approach will be chosen for more detailed investigation. These configuration studies are supported by studies of electric power requirements, life support systems, dynamics and control systems and many more supporting research studies at the NASA research centers and industrial laboratories.

In parallel with the MOL configuration investigations, feasibility studies of various ferry vehicles are being undertaken. This includes modified Gemini and Apollo ferries as well as conceptual studies of large ballistic and lifting body spacecraft, although it is quite clear already that the early MOL can use only modified existing spacecraft. Tying together all of the large station logistics demands is a separate study of MOL operations and logistics.

The results of all these studies are being thoroughly analyzed at NASA Headquarters with the purpose of selecting that MOL concept which satisfies the various demands of cost, schedule, technical usefulness, reliability and safety and preparing a sound development plan for the program. Since the Manned Orbital Laboratory is such a basic research tool for any future manned space operations, there is no question that, eventually, it will become a reality. The question is when and in what form.

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LIST OF FIGURES

ROTATIONAL PARAMETERS AND HUMAN COMFORT ZONE

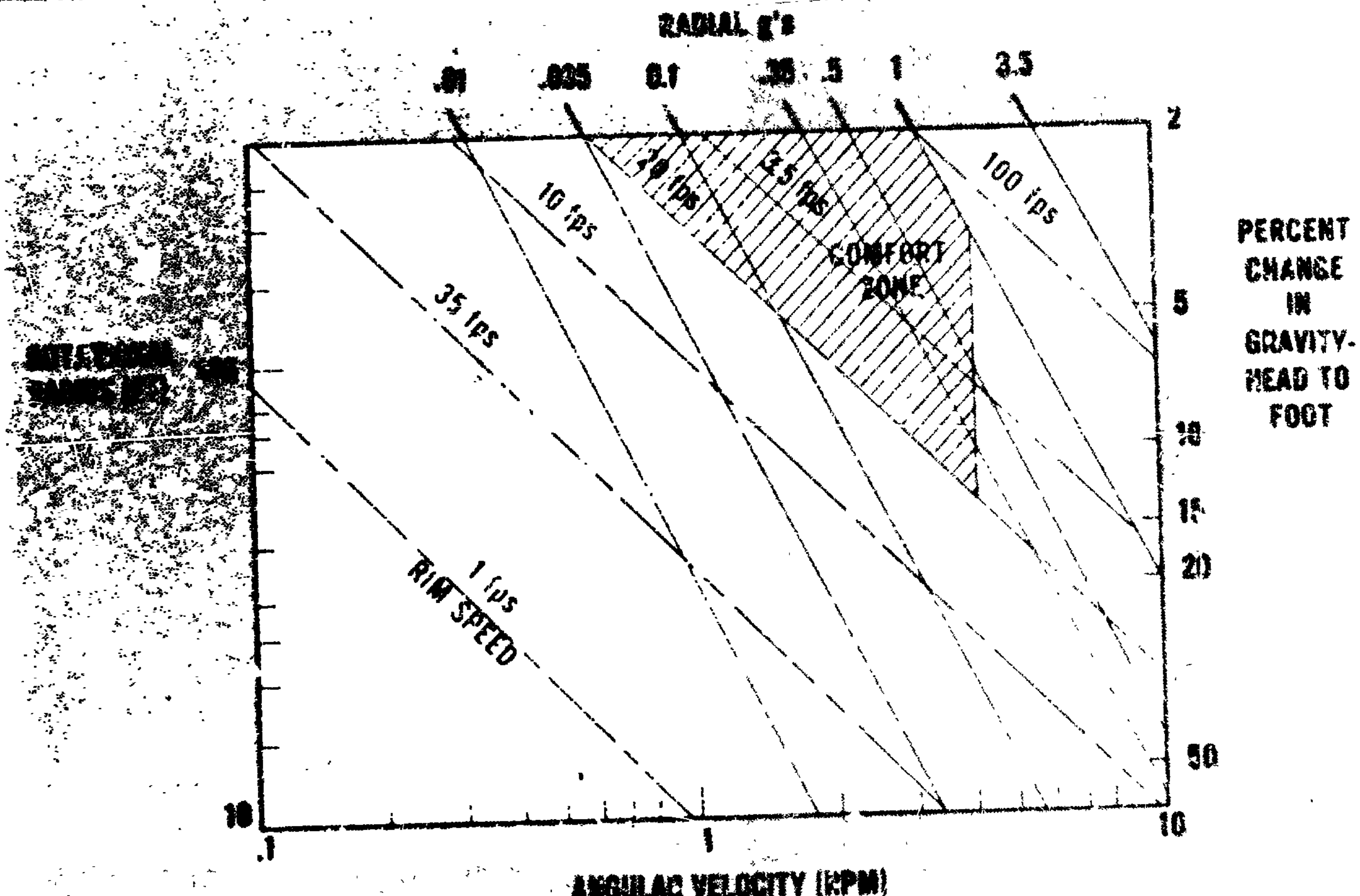


Figure 1

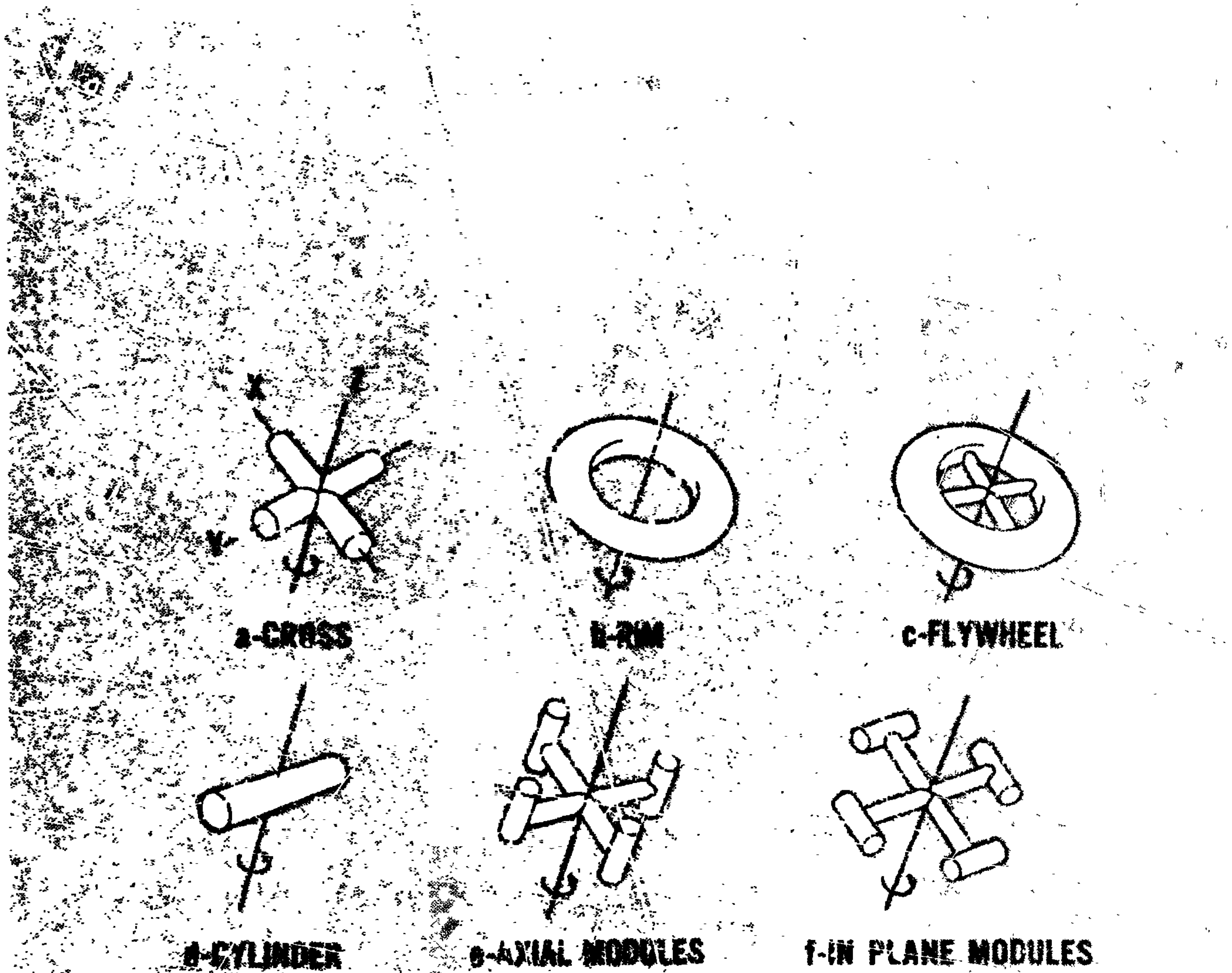
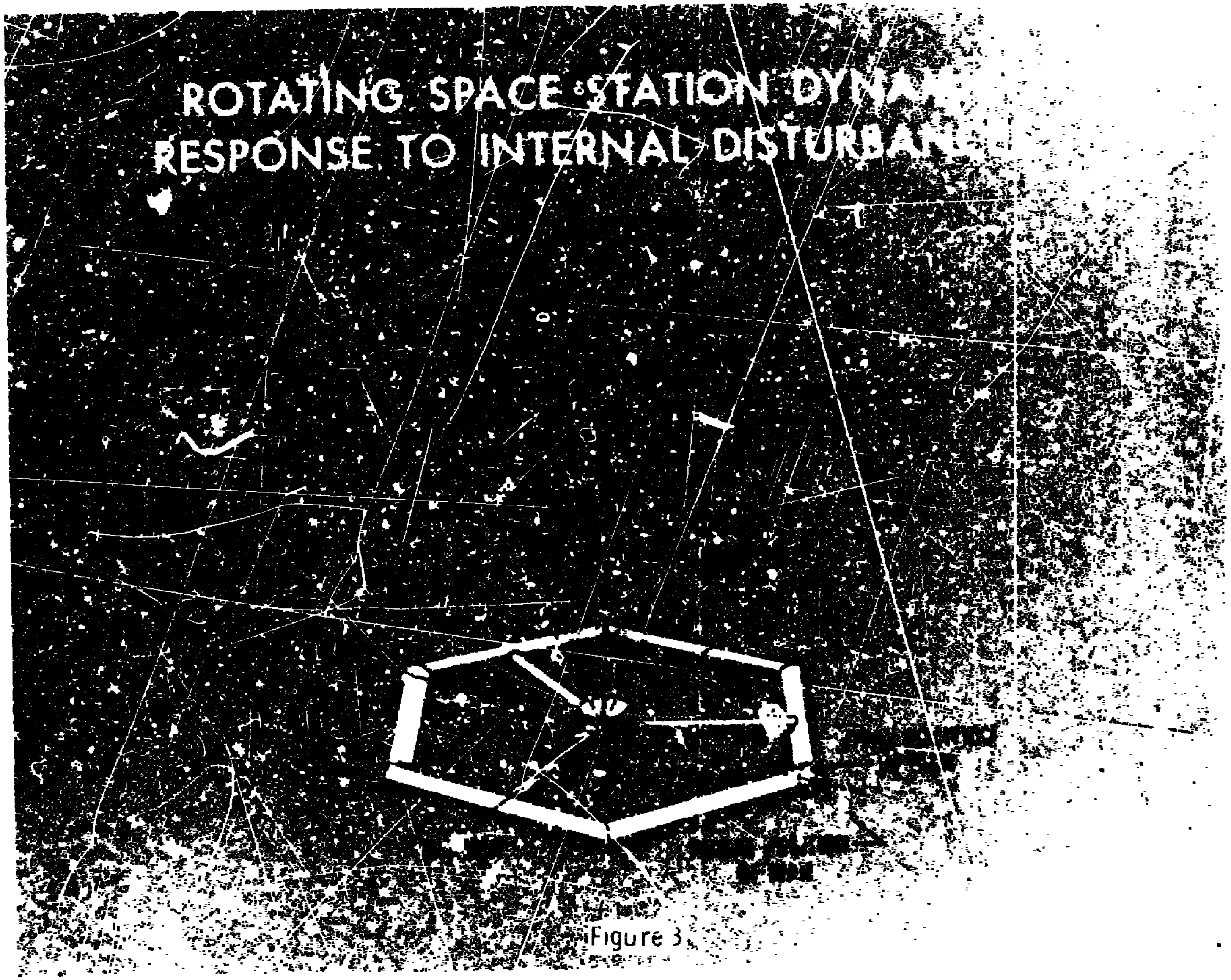

X
Y
a-CROSS
b-RIM
c-FLYWHEEL
d-CYLINDER
e-AXIAL MODULES
f-IN PLANE MODULES

Figure 2


ROTATING SPACE STATION DYNA
RESPONSE TO INTERNAL DISTURBA
Figure 3

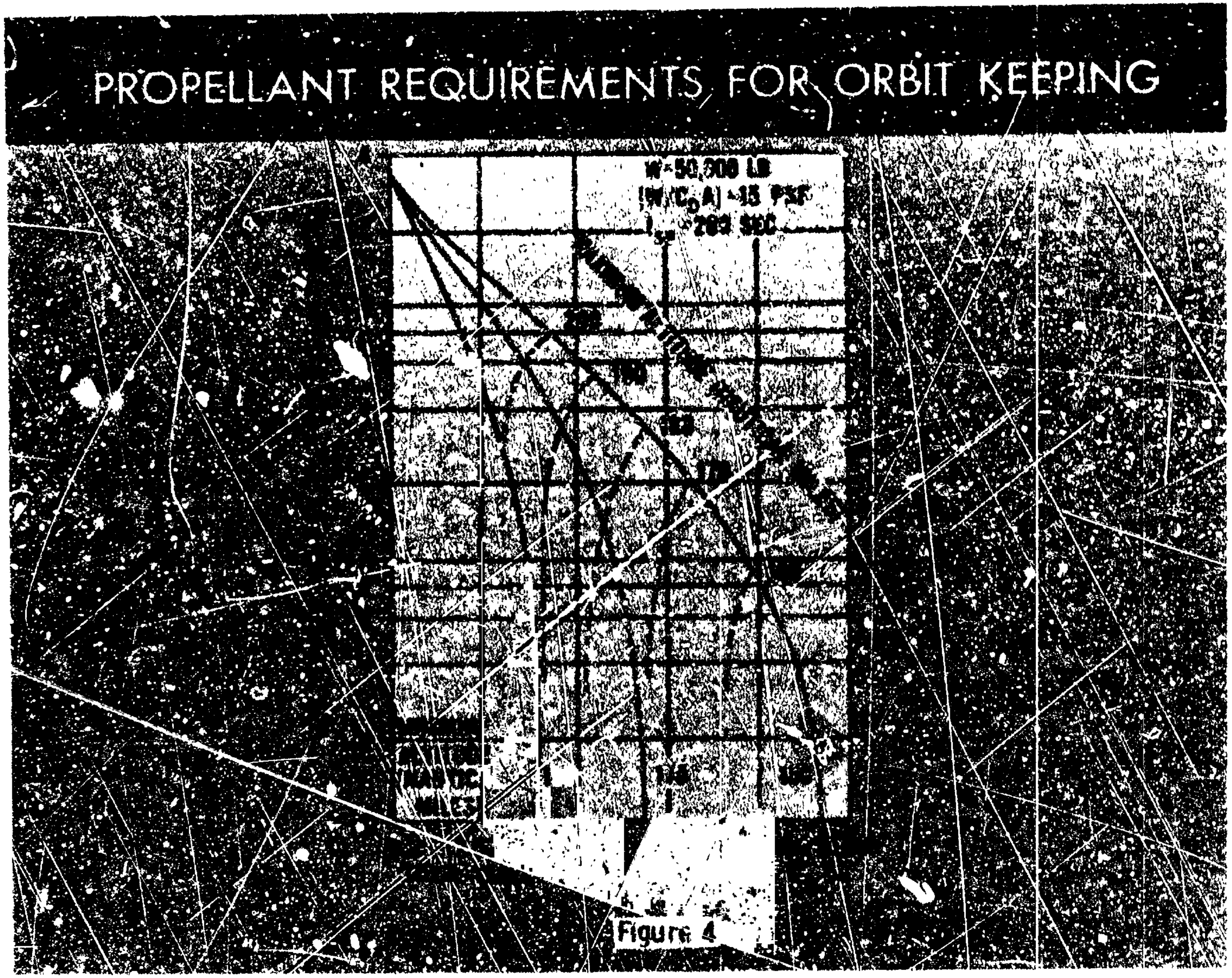


Figure 4

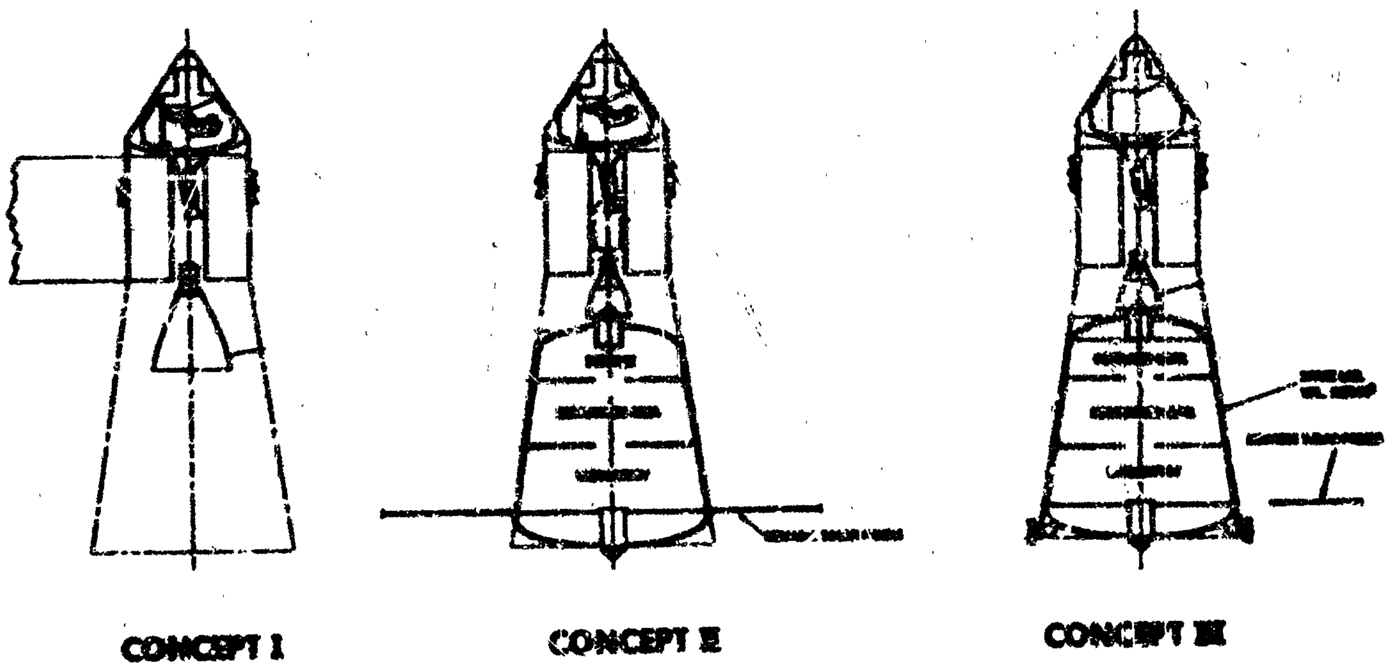
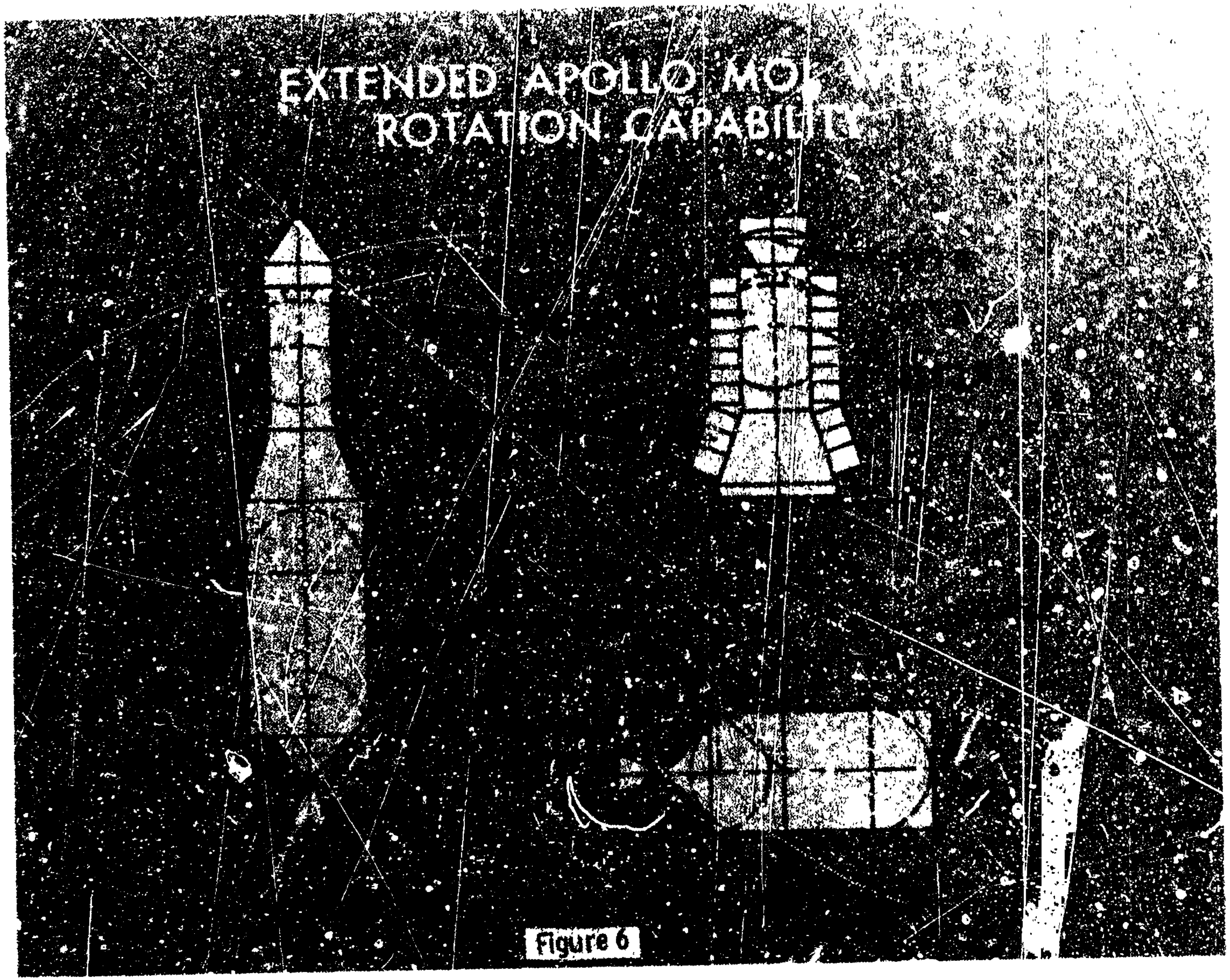


Figure 5


EXTENDED APOLLO MO
ROTATION CAPABILIT
Figure 6

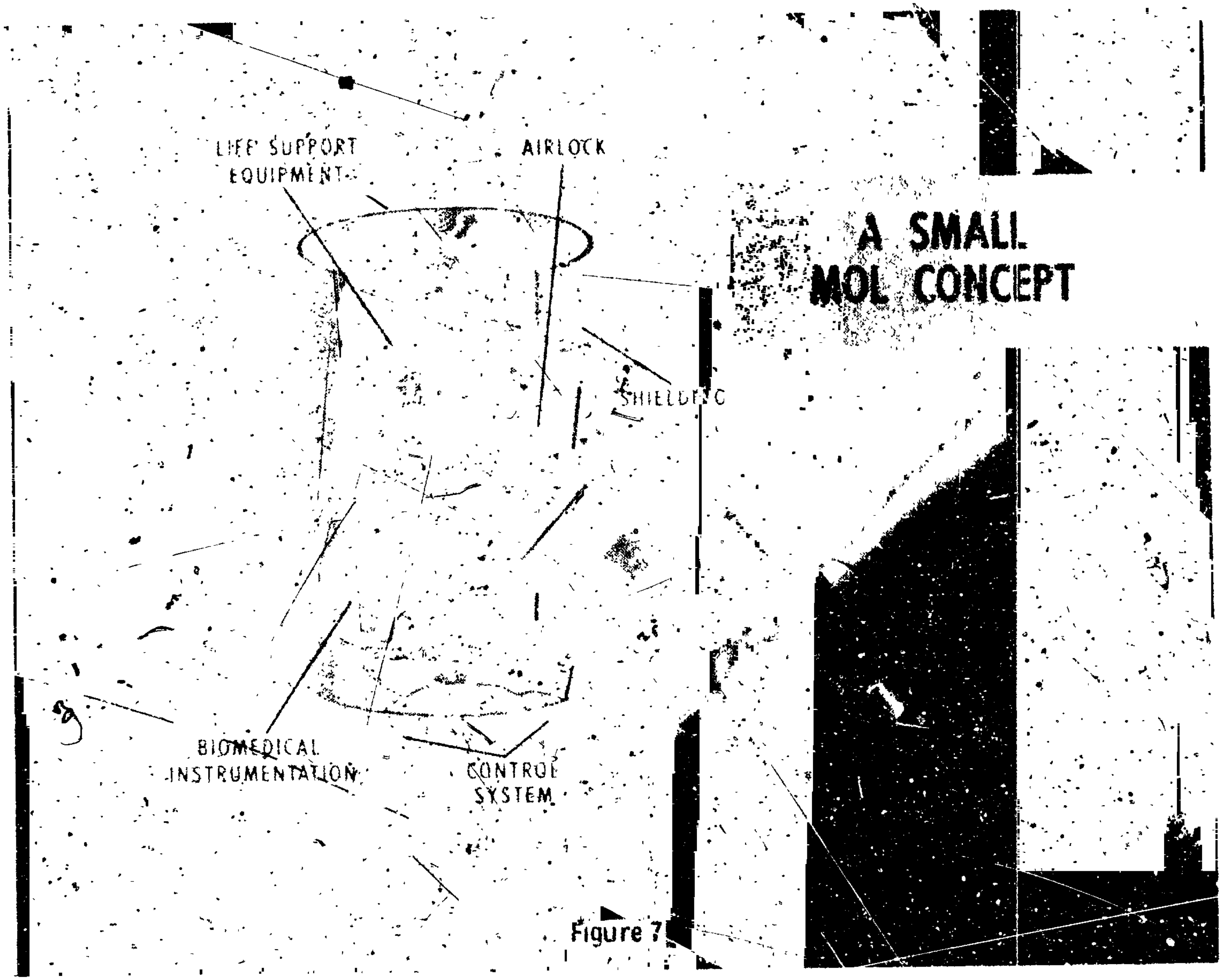

A SMALL
MOL CONCEPT
LIFE SUPPORT
EQUIPMENT
AIRLOCK
SHIELDING
BIOMEDICAL
INSTRUMENTATION
CONTROL
SYSTEM

Figure 7

A SAMPLE CREW ROTATION SCHEDULE

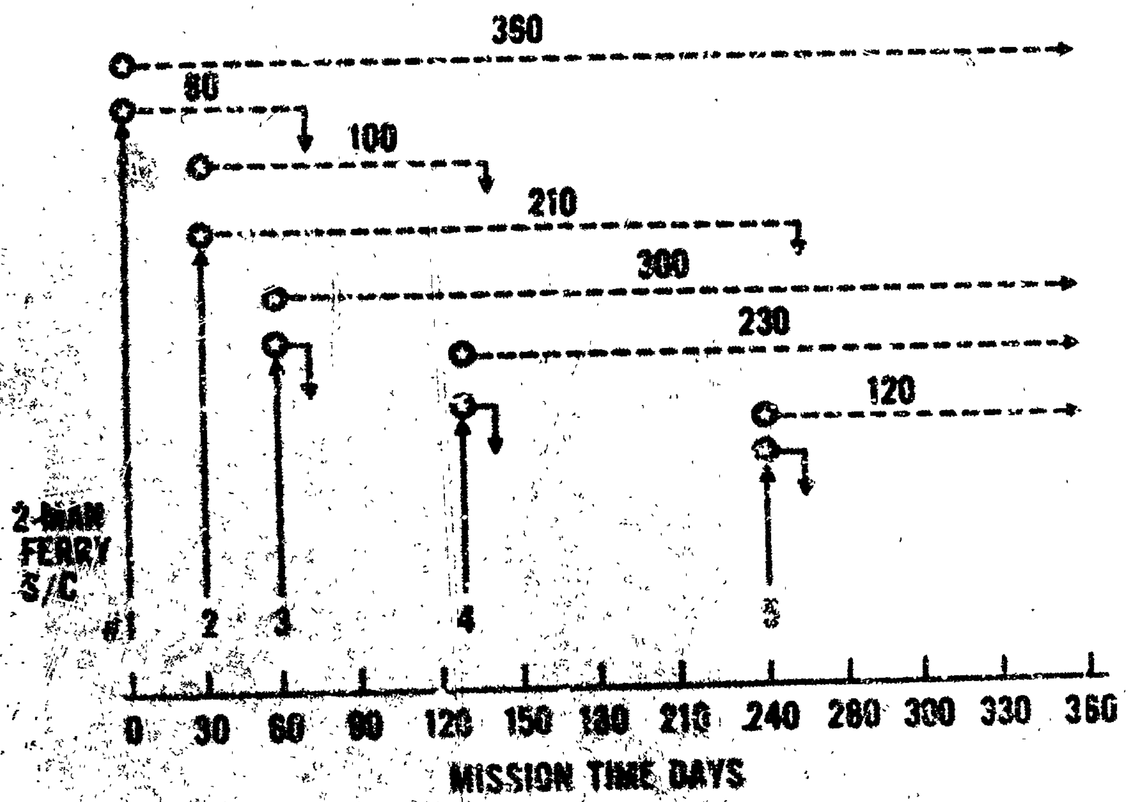


Figure 8

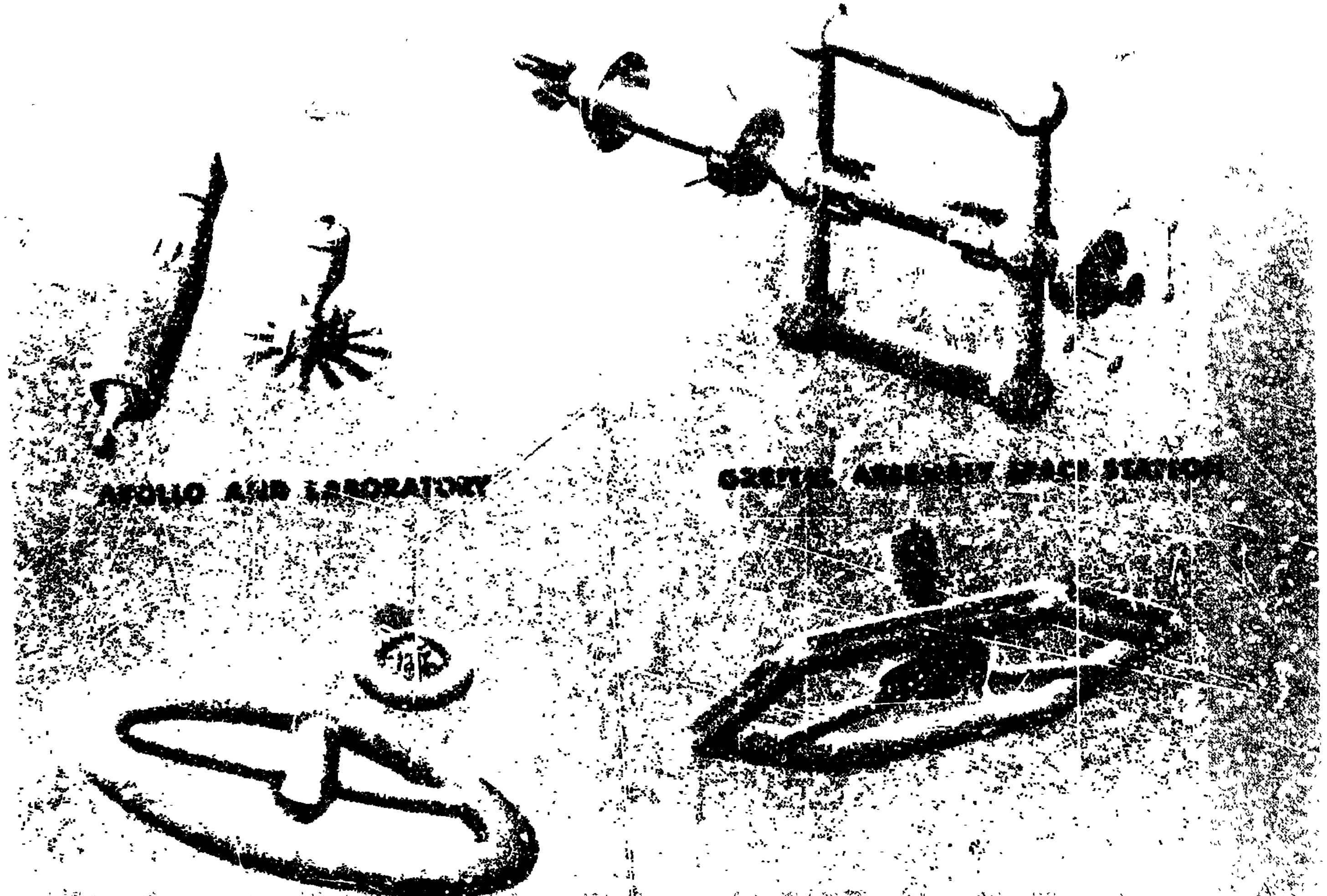


Figure 9

INFLATABLE STRUCTURE SPACE STATION MODIFIED TOROIDAL SPACE STATION

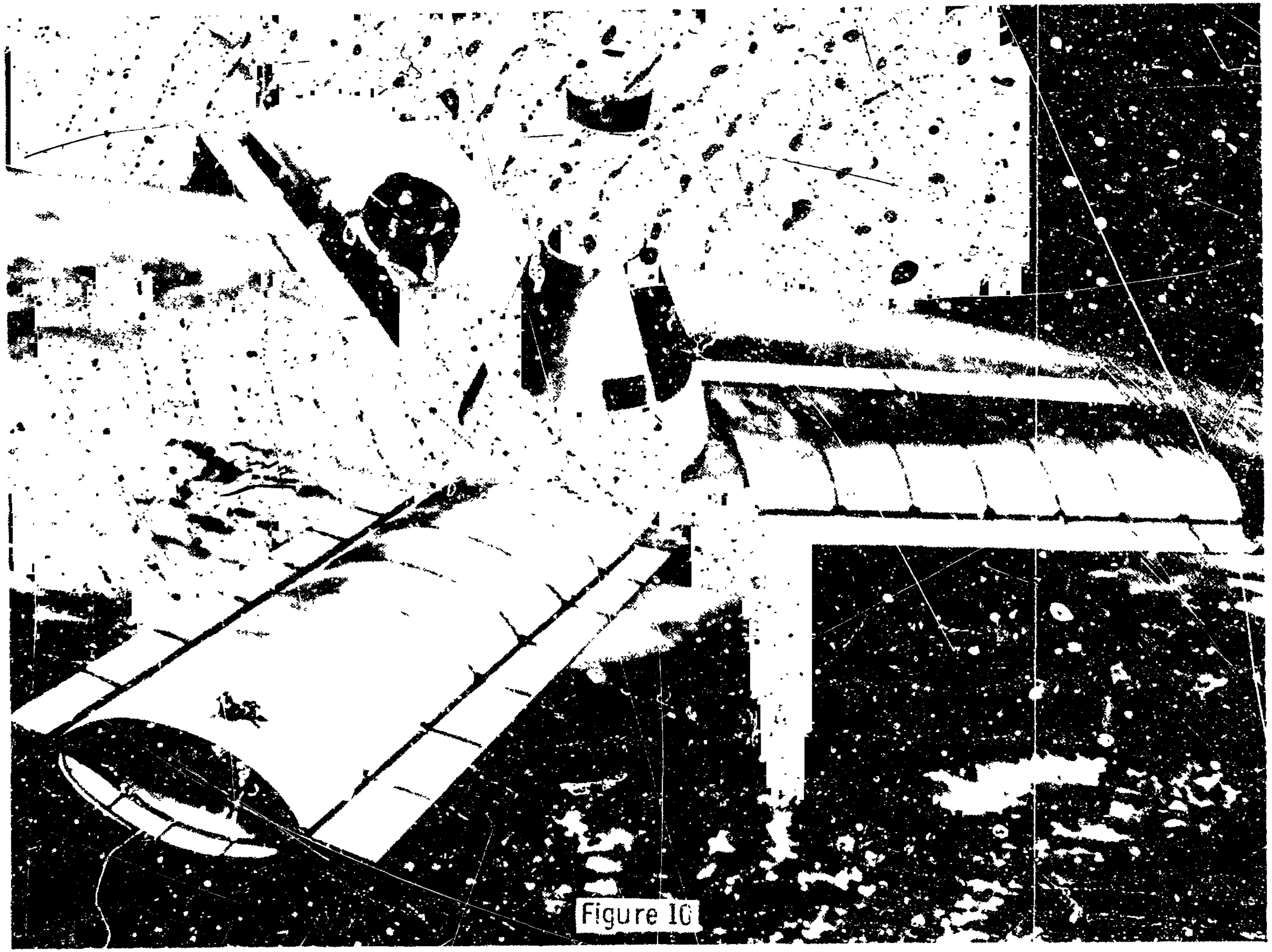


Figure 10

TYPICAL RADIAL MODULE ELEMENT

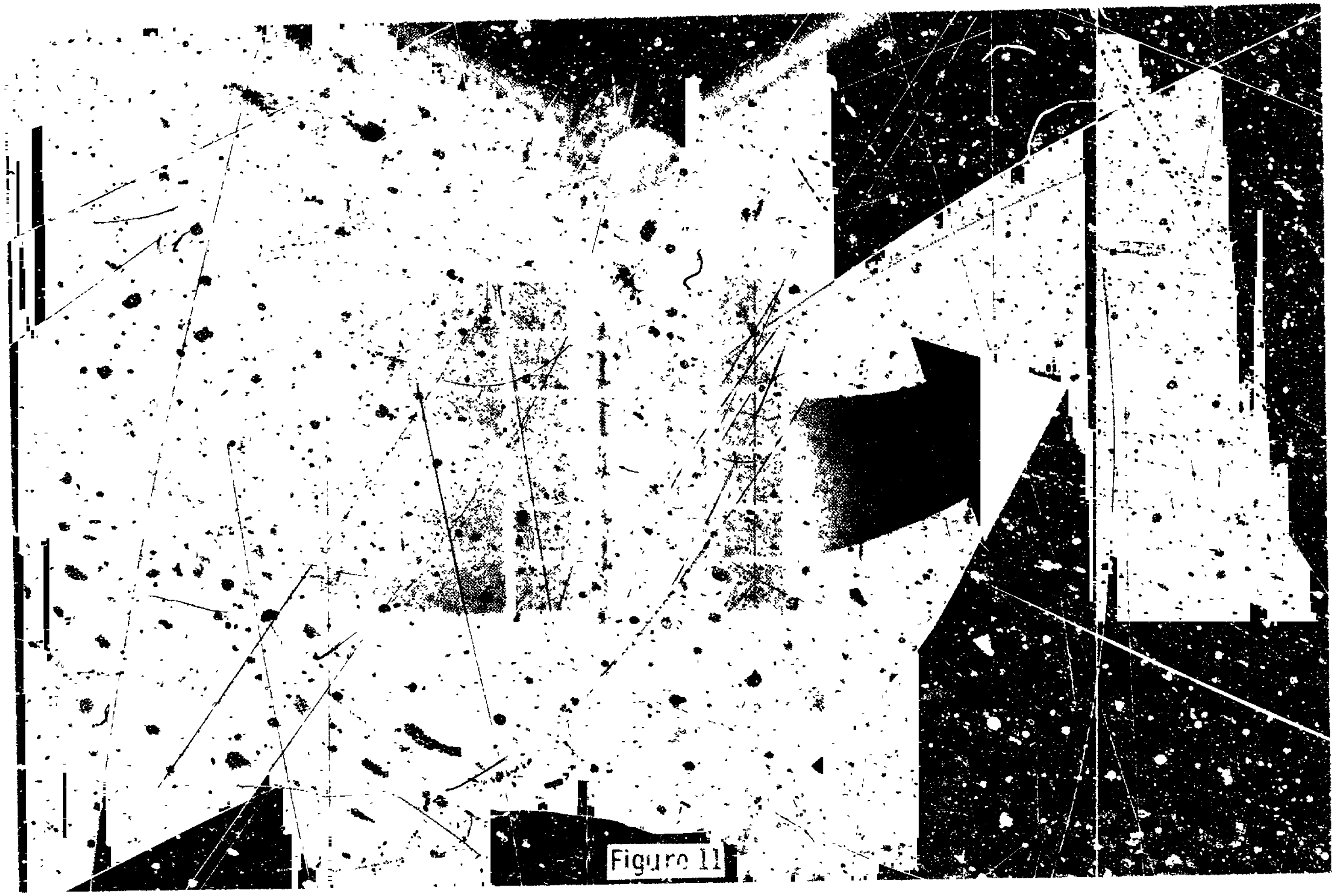


Figure 11

LARGE MOL MISSION SEQUENCE

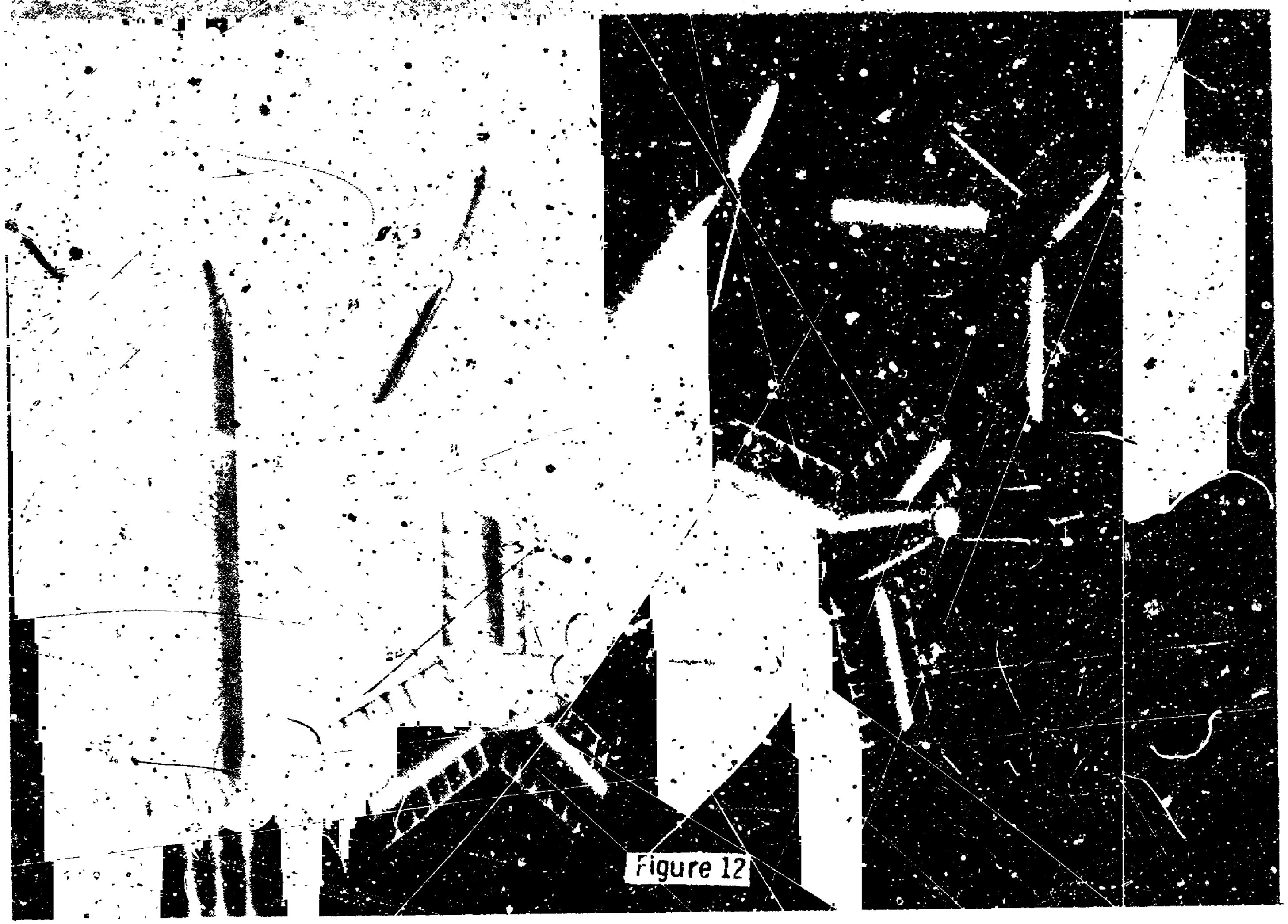


Figure 12

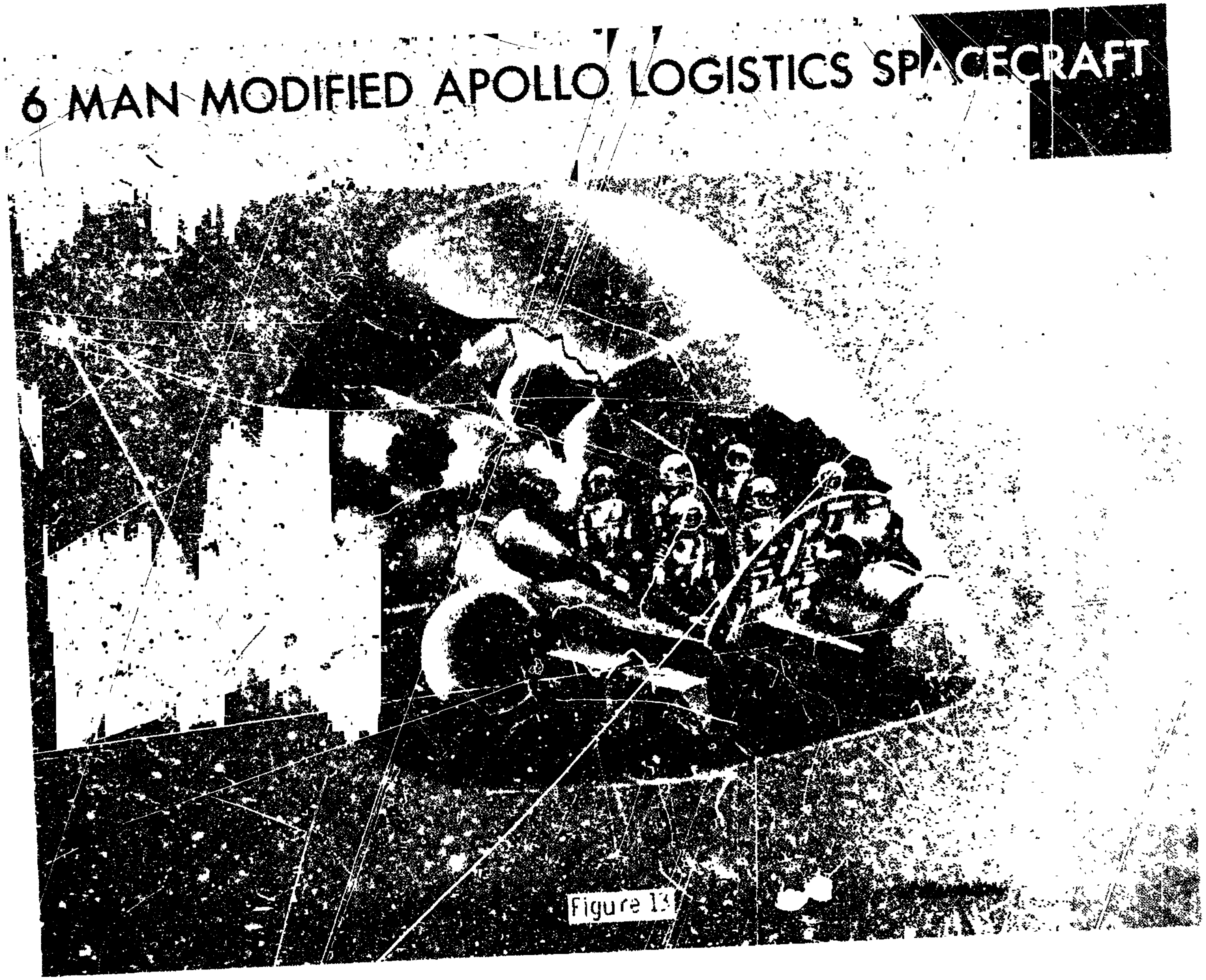


Figure 13